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Human Factors Evaluation of Electronic Chart Display and Information Systems (ECDIS)

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RESEARCH & DEVELOPMENT CENTER
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16. Abstract

This report describes a study done to examine the contributions that ECDIS might make to the operational practices on the commercial bridge. Issues examined were: the contribution to the safety of navigation, the effect on the navigational workload, the features required during route monitoring, and the potential contribution of integration with radar.

Two commercially-available ECDIS devices were installed on the simulator bridge at MSI/CAORF. Expert mariners made repeated port arrivals and departures. A variety of ship and mariner performance measures were collected and extensive debriefings were conducted.

ECDIS demonstrated the potential to increase safety, primarily by decreasing the cross track distance from a planned track, and the potential to decrease the workload of route monitoring, primarily by replacing time-consuming plotting on the paper chart. For route monitoring, mariners required only a simple display outlining safe water, but recommended access to a larger set of chart features as reference. Radar integration, as implemented on the devices used, did not provide the ARPA information mariners required.

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METRIC CONVERSION FACTORS

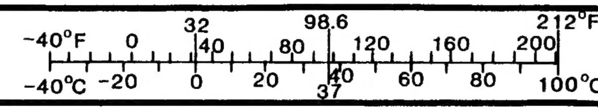
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (WEIGHT)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (EXACT)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly).

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (WEIGHT)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (EXACT)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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EXECUTIVE SUMMARY

INTRODUCTION

In the last few years, the Electronic Chart Display and Information System (ECDIS) has emerged as a powerful addition to the modern bridge, offering the possibility of effecting major changes in the navigation process and improving the safety and efficiency of maritime operations. By superimposing chart, ship's real-time position, and radar on one display, ECDIS has the potential to improve the accuracy of navigation, increase awareness of dangerous conditions, and reduce the mariner's workload. This report describes an examination of these potential effects using the special capabilities of a full-mission ship's bridge simulator.

PURPOSE

There were two purposes for conducting this study. One was to contribute to the United States' position on the International Maritime Organization's (IMO) Performance Standards (PS) for ECDIS. Another was to examine the contributions that the new ECDIS technology might make to operational practices on the commercial ship's bridge, to identify the conditions under which these contributions will be made, and to identify developments needed before ECDIS can make its best potential contribution.

OBJECTIVES AND SCOPE

The study was designed to consider the following four issues during the dynamic process of route monitoring:

- The potential of ECDIS to contribute to safe navigation
- The potential of ECDIS to reduce the navigational workload
- The chart features and navigational functions required by the mariner
- The potential contribution of the integration of radar features on ECDIS

TECHNICAL APPROACH

Two commercially-available ECDIS devices were installed on the simulator bridge at MarineSafety International/Computer Aided Operations Research Facility (MSI/CAORF) in Kings Point, New York. The two devices offered different user interfaces, chart presentations, and radar integration for the mariners' inspection and use.

Expert mariners made repeated port arrivals and departures, using either conventional navigation procedures or one of the two ECDIS devices. The EDCIS devices were configured to operate in one of three modes -- with automatic position updating and radar features, with automatic updating and no radar features, or without automatic position updating and with the instructions to update manually. A variety of performance measures were collected, including ship position data, observer counts of ECDIS features used and navigational errors made, mariner ratings of perceived workload, and mariner reports of transit events. Extensive debriefings were conducted in order to collect reactions and recommendations from these expert mariners, based on their just-completed experience with ECDIS.

PRINCIPAL FINDINGS

Contribution to Safe Navigation

ECDIS has the potential to improve upon the safety of navigation, compared to conventional procedures. There was strong evidence that the use of ECDIS increased the accuracy of navigation, as measured by a smaller cross-track distance of the ship from the planned track line, and reduced the proportion of time spent on navigation, with a corresponding increase in the proportion of time spent on the higher risk collision avoidance task. In addition, ECDIS was shown to improve geographic "situational awareness," and to reduce navigation "errors."

Reduction in Mariner Workload

The strongest and most consistent finding was that the availability of ECDIS on the bridge substantially reduces the mariner's workload for navigation. Mariner ratings of workload decreased significantly with ECDIS, they used a smaller proportion of time on navigation, and made spontaneous comments such as: "Navigation goes away as a task."

The ECDIS devices had no effect on the workload for collision avoidance or for bridge management. In order to reduce workload for these tasks, ECDIS must have a user friendly integration of all Automatic Radar Plotting Aid (ARPA) features and must automate such functions as gear testing and record-keeping.

Mariners' Requirements for System Characteristics, Chart Features and Navigational Functions

This study identified a number of system characteristics required for the effective use of ECDIS for route monitoring in the Coastal and Harbor/Harbor Approach phase of navigation: all charted information must be accurate, updating of own ship's position must be accurate and automatic, scaling of own ship in narrow channels must be accurate, and a selected subset of chart features must be always available. The safety of ship control requires a detailed and accurate view of the immediate surround. In addition, a larger set of chart features must be available for reference and navigation functions must be implemented in a user-friendly manner.

Two sets of requirements for chart features were identified. For the dynamic function of route monitoring, only a very simple subset of chart features, features that outline the safe water available for the transit was required. These included: coastline/ landmass, fixed and floating aids to navigation, federal channel lines, navigation lanes and fairways, and isolated dangers. These features are all in the "display base" or "standard display" of the IMO Performance Standards. A much larger subset of charted features was seen as serving a static function as a geographic information system (GIS), available for reference as needed but not cluttering the screen. Examples of these were: soundings, depths, bottom contours, aids to navigation characteristics, names of points, etc.

Mariners recommended that navigation functions, such as planned track line or own ship outline, be developed with the inclusion of the end user; that they not lead to a system that is overly complicated, cluttered and confused; and that there be sufficient standardization so that an experienced mariner can make immediate, effective use of a different system.

Contribution of Radar Integration

The study also examined the potential contribution that the integration of ECDIS and radar might make to navigation performance, beyond that made by ECDIS used with a separate radar. This study found that the integration of radar features on the experimental ECDIS devices had no measurable effect on the safety of navigation. Mariners expressed an increase in confidence in the accuracy of positioning but no effects on trackkeeping or on any measure of navigation workload were found.

The traffic-dense port arrivals and departures required frequent attention to collision avoidance. One of the ECDIS devices provided a full radar overlay and the other provided

only ARPA targets. Both provided some ARPA-type information. Mariners, however, made heavy use of the separate radar/ARPA on the bridge in all conditions, reporting that only the complete ARPA was adequate for their needs. The integrated systems were not adequate and no reduction in the workload of collision avoidance was found.

To achieve a more effective integration of ECDIS and radar, it is recommended that users have the option of selecting between display of complete radar video and ARPA targets only, that complete ARPA information be available, that the screen be kept uncluttered by simplifying the chart display and by minimizing sea/rain clutter.

ECDIS as Automation

In the words of one of the participating mariners, "The units are more than replacements for the chart -- they are replacements for human activity." Many of the ECDIS issues considered during this study are generic to the use of automated systems. These include the effects of automation on safety, on workload, on situational awareness, etc. Because of the broad implications of such issues for maritime safety, the USCG is involved presently in a major study of the effects of shipboard automation on human performance. A broad range of activities to examine changes in mariner functions, including user-interface evaluation, workload studies, requirements analyses, and training and qualifications analyses, will provide the USCG with the data and procedures that will support all stages of the system design and regulatory development process.

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1.0 INTRODUCTION

1.1 EXAMINATION OF THE MARINER'S USE OF THE ELECTRONIC CHART DISPLAY AND INFORMATION SYSTEM (ECDIS)

1.1.1 Examination of a New Technology

In the last few years, the Electronic Chart Display and Information System (ECDIS) has emerged as a powerful addition to the modern bridge, offering the possibility of effecting major changes in the navigation process and improving the safety and efficiency of maritime operations. By superimposing chart, ship's real-time position, and radar on one display, ECDIS has the potential to improve the accuracy of navigation, increase awareness of dangerous conditions, and reduce the mariner's workload. Because this is a new technology, there are complex engineering, operational, and human operator issues to be explored before ECDIS can make its maximum contribution. This report describes an examination of the human operator's use of ECDIS, employing the special capabilities of a full-mission ship's bridge simulator.

1.1.2 Purpose

The United States Coast Guard's (USCG) first purpose in conducting this study was to contribute to the United States' position on the International Maritime Organization's (IMO) Performance Standards (PS) for ECDIS (International Maritime Organization, 1989, 1994).

A second purpose is to collect operator-in-the-loop performance data on a shiphandling simulator to determine how an ECDIS will be used on a bridge, to determine the situations in which it enhances navigation, and to determine further design developments needed for wide-scale use in the maritime industry.

A secondary purpose was a methodological one: to select and examine the procedures and performance measures that might be used in later, related simulator studies or in sea trials.

1.1.3 Objectives and Scope

The IMO Performance Standards were reviewed and several issues were selected for examination. Criteria for the selection were that the issues be very central to the Standards, that they have broad implications for operational use of ECDIS, and that the shiphandling simulator be an appropriate tool for their investigation. The study was designed to consider the following four issues during route monitoring.

1. The potential of ECDIS to contribute to safe navigation (IMO PS, Item 1.1). To allow the demonstration of potential effects on safety, scenarios were designed with the relatively high risk conditions of port arrivals and departures with surrounding traffic and narrow channels. ECDIS should provide equal or better quality and timeliness of information to the mariner for the control of the vessel, compared to conventional methods of navigation. The quality of information provided was evaluated by comparing the precision of navigation (trackkeeping) using ECDIS, with performance using conventional methods.

2. The potential of ECDIS to reduce the navigational workload (IMO PS, Item 1.6). The potential of ECDIS to reduce workload was examined under the relatively demanding conditions of a one-officer bridge during arrivals and departures. A primary value of an automated system should be the reduction of operator workload, compared to conventional methods of navigation. A reduction in workload suggests an increase in safety as the mariner has more time for monitoring and "look-out." To evaluate the importance of an automatic positioning input to a potential reduction in workload, scenarios with a "failure" of the positioning system were included.

3. The chart features and navigational functions required by the mariner (IMO PS, Items 1.4 and 3 and Appendix 2). Whether ECDIS will contribute to safe navigation and reduce workload depends on whether all the required chart features and navigational functions are available to the mariner. The availability of the required features and functions is especially critical during the real-time operation of route monitoring. The mariners' use of features and functions available on the experimental systems was observed during the scenarios and the mariners were questioned about a more extensive list of potential items.

4. The potential contribution of the integration of radar features on ECDIS (IMO PS, Item 6). The integration of electronic chart, vessel position, and radar on one scope offers the possibility of greater awareness of dangerous conditions and further reduction of mariner workload. There is as yet no agreement as to what such a system should look like. The experiment evaluated performance with both an overlay of the complete radar video and a radar overlay that contained only ARPA targets.

Planning during Phase I of the reported project involved a literature search and the generation of an exhaustive catalogue of questions concerning the utility and implications of a wide variety of ECDIS features and functions. This process is described in "Proposal for an ECDIS Research Program," (MSI/CAORF staff, 1991)

1.2 BACKGROUND

1.2.1 International Maritime Organization's (IMO) Performance Standards for ECDIS

In 1989 the IMO issued Provisional Performance Standards (PPS) for Electronic Chart Display and Information Systems (ECDIS) (International Maritime Organization, 1989), and allowed time for participating nations to evaluate these standards and to submit recommendations on their adequacy. The USCG goal in sponsoring this simulator evaluation was to contribute to the U.S. position on the Standards. The 1989 version was a major consideration in the planning of the present study. In 1994, the Performance Standards (PS) for Electronic Chart Display and Information Systems (ECDIS) (International Maritime Organization, 1994) was issued. Because the study was planned around larger issues addressed by the Standards, the findings are as relevant to the 1994 version as they were to the 1989 version. A summary of the experiment's findings on the Standards is presented in Appendix F of the present report.

1.2.2 International Maritime Organization's (IMO) Annex 1 List of Matters for Use in Examining Subject Areas Which May Have Human Factor Implications

The IMO's Marine Safety Committee has distributed Annex 1 List of Matters for Use in Examining Subject Areas Which May Have Human Factor Implications (International Maritime Organization, April 1992) to its various Sub-Committees. The IMO Human Factors List is intended as a diagnostic tool, to be used to examine a system or procedure to determine whether it has human factors implications that might require further study. The

factors included in the List for consideration were reviewed for application to the mariner's use of ECDIS for watchstanding (International Maritime Organization, August 1992).

1.2.3 United States Coast Guard's Integrated Navigational Systems (INS) Program

The human factors study reported here is a component of the comprehensive Research, Development, Test and Evaluation (RDT&E) program being conducted by the USCG Research and Development (R&D) Center to assess the operational capabilities and limitations of ECDIS. The Office of Coast and Geodetic Survey (C&GS) at the National Ocean Service, NOAA and USCG are leading participants in a joint government-industry research project to evaluate the Standards for ECDIS (International Maritime Organization, 1994). In addition, the USCG is evaluating the Radio Technical Commission for Maritime Services (RTCM) Recommended Standard for Electronic Chart Systems (ECS) (Radio Technical Commission, 1994).

Various prototypes and commercially available systems have been tested. During October 1991, the USCG R&D Center conducted a series of at-sea experiments onboard the U.S. Merchant Marine Academy T/V KINGS POINTER (Gonin and Crowell, 1992). Between January and April of 1993, the USCG R&D Center conducted human factors sea trial tests using ECDIS aboard the USCG Cutter BITTERSWEET and the new Motor Vessel KINGS POINTER (Gonin and Dowd, 1994). Additional at-sea evaluations are planned onboard a variety of vessels and various USCG cutters/boats. A joint research program agreement (JRPA) has been established between the United States and Canada to conduct joint RDT&E of ECDIS and ECDIS-related technologies (Alexander and Casey, 1992). Under this U.S./Canada JRPA, a small scale human factors simulator test using ECDIS was conducted at the Centre for Marine Simulation (CMS) in St. John's Newfoundland (Center for Marine Simulation, 1994).

The findings of the U.S. RDT&E Program on ECDIS supported the development of the IMO Standards for ECDIS and will continue to support the development and operational implementation of this important, new technology.

1.2.4 Earlier Investigations of the Use of Electronic Navigation Systems

The USCG has had an active human factors research program under way for more than a decade to examine the potential effects of new, developing technologies on navigational performance. The program has focused on the effectiveness of electronic displays for the specific operation of harbor/harbor approach piloting, especially in reduced visibility. Systems have been examined both at sea (Cooper and Bertsche, 1981; Roeber, 1981) and on real-time man-in-the-loop shiphandling simulators. These investigation provided many of the experimental procedures and measures discussed in Section 4 of this report.

A review of the earlier studies also provided hypotheses on the performance effects to be expected with ECDIS. It has been demonstrated that the precision of navigation and mariner acceptance of a new technology were very sensitive to differences in specific display features (Smith, 1993; Mandler and Smith, 1990; Mandler, Smith, and Gynther, 1990-1991; Smith, Mandler, Mazurkiewicz, Gynther, and Brown, 1990; Gynther and Smith, 1989; Cooper, Marino and Bertsche, 1981a; Cooper and Marino, 1980). The expected importance of specific features was one reason for including two different commercial systems in the experiment. Together, they gave the mariners the opportunity to examine and use a wider range of features than either alone. Earlier studies demonstrated the influence of positioning accuracy on the effectiveness of navigation systems in supporting ship control and on mariner reaction (Gynther and Smith, 1989; Cooper, Marino, and Bertsche, 1981b). While the accuracy of the positioning input was not varied in this experiment, these earlier findings, together with the negative reactions of mariners in this experiment to such inaccuracies as digitizing errors in the electronic chart and unscaled ship icons, support a conclusion that display accuracy is important to ECDIS function. Findings of earlier studies provided an expectation that mariners would value a radar overlay, to monitor both positioning accuracy and the action of traffic (Smith, 1993). The relevance of many of these past investigations of electronic navigation to ECDIS design was reviewed in a recent paper (Smith and Mandler, 1992).

The Computer Aided Operations Research Facility, now MarineSafety International/ Computer Aided Operations Research Facility (MSI/CAORF), has a history of experimentation in the mariner's use of advanced bridge equipment. Examples include investigations of the use of displays for ship positioning and navigation (CAORF Research Staff, 1978a) and for collision avoidance (Schryver, 1983; Aranow, 1979; Hayes, 1979; CAORF Research Staff, 1978b). More complex integrated displays have also been investigated

(Williams, Goldberg, and Nieri, 1982; Hayes and Wald, 1980). In some cases, these developing technologies were applied to specific operational problems (O'Hara and Brown, 1985). These CAORF studies also contributed to the hypotheses and the experimental procedures of the present study.

1.3 USE OF A SHIPHANDLING SIMULATOR FOR SYSTEM EVALUATION

1.3.1 Simulator Evaluation of System Performance

A full-mission shiphandling simulator is a powerful tool for the evaluation of ECDIS. The use of simulation to evaluate operator-machine system performance in the marine environment is a well-established practice (Smith, 1993; Smith and Mandler, 1992; O'Hara and Brown, 1985; Reik and Hargis, 1981). Simulation, when used as a test platform, provides many capabilities not possible in real-world evaluations. These include the capability: to concentrate only on events of high interest, to control all aspects of the external environment, to replicate tests, to examine relatively high-risk conditions, and to monitor and record many aspects of system and human performance. The ECDIS test plan was intended to maximize the advantages of a simulator test bed by selecting those issues most effectively or efficiently examined there. The simulation exercises, therefore, consisted primarily of route monitoring in the relatively high risk coastal and harbor/harbor approach phases of navigation during vessel arrivals and departures from port (Federal Radionavigation Plan, 1992). Passage planning was addressed only by having the participating mariners perform a brief exercise and consider such a use based on their experience with the systems during the route monitoring simulation tests. Engineering aspects of ECDIS technology and those human factors issues better evaluated through longer mariner exposure to the technology were not considered. Thus, topics like system reliability, chart correction, and vigilance were excluded from the simulation evaluation on the assumption that they could better be evaluated during real-world test bed trials.

1.3.2 Use of the MarineSafety International/Computer Aided Operations Research Facility, MSI/CAORF

The MSI/CAORF simulator has many capabilities for the effective conduct of human factors evaluations of vessel operations. As an example, the simulator facility is equipped with a human factors monitoring station from which an experimenter can closely watch and record activities on the bridge and from which all simulation parameters can be recorded for

later detailed analysis. In addition, the modular design of the bridge permits reconfiguration of the bridge instrumentation. The resident engineering staff was available for the required integration of the commercial ECDIS devices with the existing bridge suite during the first phase of this project (MSI/CAORF staff, 1991). This integration required staff engineers and data base programmers who were familiar with the simulation systems, the ECDIS technology, and the project objectives. A more detailed description of CAORF capabilities appears in Appendix A.

1.4 OVERVIEW OF THE REPORT

The remainder of this report is organized as follows:

SECTION 2.0 SIMULATION AS A "TEST BED" FOR ECDIS EVALUATION describes briefly the two commercial ECDIS devices that were selected and the configuration of the MSI/CAORF simulator for the experiment. Both the systems and the simulator features used in the experiment are described further in Appendix B.

SECTION 3.0 EVALUATION PLAN includes a description of the experimental design, the scenarios, and the participating mariners. Samples of the instructions are presented in Appendix C.

SECTION 4.0 PERFORMANCE MEASUREMENT describes the variety of performance measures that were selected or developed to benefit from the capabilities of the simulator in examining the complex task of watchstanding. Additional discussion and sample data collection forms and questionnaires are presented in Appendix D.

SECTION 5.0 RESULTS AND DISCUSSION: CONTRIBUTION OF ECDIS TO SAFETY AND WORKLOAD IN ROUTE MONITORING is the primary result section. It presents and discusses the findings comparing route monitoring using ECDIS to route monitoring done using conventional methods. Both simulator measures and mariner reactions are reported. Additional data not included in the discussion in Section 5.0 are presented in Appendix E.

SECTION 6.0 RESULTS AND DISCUSSION: ROLE OF ECDIS FEATURES IN ROUTE MONITORING presents findings on the use of chart features and ECDIS-based navigation functions. Both experimenter observations and mariner creactions are reported. Additional material is presented in Appendix E.

SECTION 7.0 RESULTS AND DISCUSSION: ROLE OF ECDIS-BASED RADAR FEATURES IN ROUTE MONITORING presents findings on the use of ECDIS radar features during route monitoring. Additional material is presented in Appendix E.

SECTION 8.0 CONCLUSIONS contains conclusions that follow from the results in Sections 5.0, 6.0, and 7.0. A table containing an item-by-item listing of the IMO PS accompanied by a summary of relevant findings for each item appears in Appendix F.

2.0 SIMULATION AS A "TEST BED" FOR ECDIS EVALUATION

2.1 SELECTION OF REPRESENTATIVE ELECTRONIC CHART DISPLAY AND INFORMATION SYSTEMS (ECDIS)

Phase I of this project (MSI/CAORF Staff, 1991) included a survey and evaluation of existing, commercially available ECDIS systems to identify those most appropriate for use in this human factors evaluation. It should be emphasized that the objective of incorporating existing systems into the simulator experiment was not to evaluate any particular systems but to allow the mariners to examine and to use a number of possible configurations and features during real-time bridge operations. The criteria used in assessing the appropriateness of each candidate system were: ECDIS features, company profile, simulator/ECDIS integration, cost, and availability and delivery schedule. Two systems were selected:

- Offshore Systems Ltd.'s (OSL) Precision Integrated Navigation System - VME (PINS-VME). This system provided a demonstrated operational radar overlay capability. It was procured by the Coast Guard for both this human factors evaluation and later sea trials.

- Robertson Marine Systems Inc.'s Disc Navigation System. This system most closely conformed to the IMO Provisional Performance Standards (International Maritime Organization, 1989) at the time of the selection. Robertson Marine Systems, Inc. loaned their Disc Navigation System to MSI/CAORF for the duration of the human factors study.

2.2 DESCRIPTION OF THE SELECTED ECDIS DEVICES

The Offshore Systems Limited's (OSL) Precision Integrated Navigation System (PINS-VME) and Robertson Marine Systems Incorporated's Disc Navigation System differed from each other in many ways, the most major of which are summarized in Table 2-1. The OSL system had a single screen that could be configured by the user to present several graphic and alphanumeric windows; the Robertson system had a screen dedicated to the chart presentation and a separate liquid crystal display (LCD) to present alphanumeric information. The OSL had relatively simple, stylized charts that could be viewed in separate windows at different scales; the Robertson had a more complex, "chart-like" chart pre

Table 2-1. Major Differences Between the Two Commercial ECDIS Devices

COMMERCIAL SYSTEMS	Offshore Systems Limited PINS-VME	Robertson Marine Disc Navigation
COMPUTER	68030 @ 25 MHz	80386 @ 33 MHz
SCREEN	19 inch, 1024 x 788 pixels	25 inch, 1080 x 1040 pixels
DISPLAYS	configurable into windows, chart or text	chart on screen, text on LCD
ELECTRONIC CHART	landmass, contours, channels, aids	complex, "chart-like"
INTERFACE	touch screen and trackball	keyboard and trackball
RADAR FEATURES	video overlay, some ARPA info	ARPA targets, some ARPA info
OWN SHIP SYMBOL	scaled outline	outline not to scale

sented on the single screen. The OSL presented complete radar video as an overlay to the chart and presented target range and bearing information in an alphanumeric window; the Robertson system presented only the targets acquired by the separate ARPA on the bridge and their vectors on the chart display and presented range, bearing, closest point of approach (CPA), and time to CPA on the LCD.

These systems are described in some detail in Appendix B. Specific features are described throughout the report where they are particularly relevant to the discussion. The systems are described as they were configured when they were procured and throughout the simulator tests. Significant upgrades for both systems became available during the course of the simulator experiment. However, the devices were not upgraded once testing began in order to maintain the integrity of the experimental design and to ensure continuity between test mariners. Therefore, the system capabilities described in this report are not an indica-

tion of either devices' present capabilities. This is particularly true for the OSL system which was an early prototype for the product line.

2.3 SIMULATOR AND SIMULATION MODEL CONFIGURATION

The MSI/CAORF simulator has a variety of capabilities that make it appropriate as a research simulator. It has a realistically equipped bridge from which the mariner looks out onto a 240-degree computer generated visual scene of the area being navigated. Bridge instrumentation, including radar/Automatic Radar Plotting Aid (ARPA), Doppler speed log, revolutions per minute (RPM) indicator, compass, depth sounder, ship's wheel, rudder angle indicator, etc., all operate in coordination with the visual scene to recreate a highly realistic and familiar environment for the mariner. In the background, the simulation computers accurately recreate the vessel's dynamics and its interactions with the simulated environment. A Human Factors Station (HFS) allows all bridge activities to be observed and recorded. All aspects of the simulation itself are recorded on magnetic tape for later analysis.

The simulator subsystems that played an important role in the formulation and conduct of the ECDIS evaluation included the simulation geographic model, the ship response model, the simulator bridge, and the HFS. The role and configuration of each of these subsystems are described in Appendix B.

2.4 INFORMATION TRANSFERRED FROM THE SIMULATOR TO THE ECDIS

The simulator's main computer provided data which both ECDIS devices processed as if from real-world instrumentation. This included data that mimicked feeds from Differential Global Positioning System (DGPS), gyro compass, speed log, fathometer, and apparent wind indicator (the latter for the Robertson only). Each device received radar information that mimicked what it was designed to receive on-board ship. The OSL ECDIS received raw radar data from the simulator's radar signal generator which it used to generate the radar overlay display. The Robertson ECDIS was interfaced with the Sperry RASCAR Automated Radar Plotting Aid (ARPA) and received data on targets being tracked on that device.

DGPS failure procedures were developed for scenarios for which the mariner was required to manually update the ECDIS position. Again, different procedures were needed to produce a similar "failure" on each system. For the Robertson system a DGPS failure was simulated by disabling DGPS as a navigation input and selecting the dead reckoning (DR) option. The OSL did not have a DR mode so the simulator was programmed to calculate a DR position using the ship's heading and speed through the water. The DR positions were sent to the OSL, which processed them as if they were from DGPS.

3.0 EVALUATION PLAN

3.1 ECDIS RESEARCH ISSUES AND THE EVALUATION PLAN

In recent years, as the ECDIS technology has developed, the cognizant national and international organizations have proposed or established relevant standards (International Hydrographic Organization, 1990; International Maritime Organization, 1994 and 1989; Radio Technical Commission, 1989). Early versions of these standards and a variety of industry sources were examined for research issues during Phase I of the Human Factors Evaluation of ECDIS (MSI/CAORF Staff, 1991). In addition, the IMO's Human Factors List (International Maritime Organization, April 1992) was considered. The discussion here emphasizes the IMO Performance Standards (International Maritime Organization, 1994 and 1989) and is organized by those principal issues described in this report in Section 1.1.3.

1. Contribution of ECDIS to the Safety of Navigation. The assumption in the design of this experiment was that the use of ECDIS for navigation would enhance safety by affording the watchstander an accurate and more timely knowledge of the ship's position, and its relation to a planned track and to potential hazards, than is possible with conventional bridge procedures and a paper chart. To examine the effect of ECDIS on safety, experienced mariners conducted transits under a variety of harbor, traffic, and environmental conditions, using either ECDIS or conventional procedures. The controlled, experimental nature of these exercises allowed the identification of conditions for which ECDIS would enhance safety compared to the conventionally equipped bridge.

2. Reduction of Navigational Workload by ECDIS. ECDIS can integrate information from a number of sensors and can automate the primary, and generally time-consuming, navigation function of position fixing. These capabilities should reduce the mariner's workload. It follows that a "failure" of the automatic positioning feature and the necessity to manually update the position of ownship on the ECDIS display might compromise a savings in workload. There is an implicit assumption here that reduced workload means greater safety. Established human factors procedures were used to collect ratings of perceived workload from the participating mariners for the conditions they experienced.

3. Chart Features and ECDIS-based Navigational Functions. The IMO PS (International Maritime Organization, 1994, 1989) lists required chart features and ECDIS-based navigation functions. The simulator experiment allowed the evaluation of these requirements by observing the mariners' actual selection of features and functions from the two sample devices under a variety of conditions. Extensive debriefing of the participating mariners documented their preferences on ECDIS features and allowed the extrapolation to features that were not provided by the experimental devices.

4. Integration of Radar Features on ECDIS. The issue of whether or not integrating the electronic navigation chart and radar/automated radar plotting aid (ARPA) on one device would contribute to navigation, beyond the contributions made by ECDIS used with a separate radar/ARPA, has been debated. Such integration might reduce workload by reducing the number of devices the mariner needed to consider and might improve safety by improving the quality of information available to the mariner. The capabilities of the two ECDIS devices allowed experienced mariners to examine two implementation possibilities: the overlay of a complete radar video on the electronic chart or the addition of only ARPA targets to the electronic chart. To determine whether the integration had any advantage, performance with each integration possibly was compared to performance with ECDIS and radar/ARPA as separate devices on the bridge.

3.2 EXPERIMENTAL DESIGN

Table 3-1 shows the experimental conditions in three groups: with the Offshore Systems Limited (OSL) device available on the bridge, with the Robertson Marine Systems Inc. device available, or as a baseline condition with no ECDIS available. Each ECDIS system was presented in three different modes:

- with automatic positioning update and radar overlay to allow the examination of the IMO PPS requirements for the integration of radar into the ECDIS (Scenarios 1 and 4)
- with automatic positioning update and no radar overlay as the baseline configuration for ECDIS (Scenario 2, 5, and 7)

- with no automatic positioning update to allow the examination of the IMO PS requirement that ECDIS allow the user to perform the same navigational tasks currently performed with the traditional paper chart (Scenario 3 and 6) .

The third group of conditions shown in Table 3-1 was run with only conventional equipment available on the bridge, to provide a baseline to which to compare the more novel ECDIS conditions.

Runs took place in two "harbors." OSL provided electronic charts of New York (NY) in three scales; Robertson provided charts in two scales both for NY and for San Francisco. Routes were varied to include coastal and harbor/harbor approach phases of navigation (Federal Radionavigation Plan, 1992) and to include inbound and outbound transits. Day and night and different visibilities (clear, unlimited visibility, and reduced visibility to 1 nautical mile) were included to allow varied examination of ECDIS and its radar overlays.

3.3 EXPERIMENTAL SCENARIOS

3.3.1 Experimental Scenarios and the Requirements of the Evaluation

The scenarios summarized in Table 3-1 were designed to be operationally equivalent in terms of risk, task loading, underlying task structure, and overall mission objectives. At the same time, the scenarios were designed to be different in internal content and events. These differences served several purposes. The first purpose was the requirement that ECDIS be evaluated over a wide range of realistic operational conditions and navigational regions. Second, differences in the internal content of the scenarios prevented the mariner's anticipation of events in a way that might have resulted in his performance becoming insensitive to the experimental variations in Table 3-1.

Table 3-1. Experimental Conditions

SCENARIO	HARBOR	ROUTE	VISIBILITY	ECDIS POSITION	RADAR/TARGET OVERLAY
OFFSHORE SYSTEMS LTD PINS-VME					
1	NY	inbound: coastal, harbor	reduced visibility	automatic update	yes
2	NY	inbound: coastal, harbor	clear/ day -night	automatic update	no
3	NY	outbound: harbor	reduced visibility	manual/ radar overlay	yes
ROBERTSON MARINE SYSTEMS INC DISC NAVIGATION					
4	NY	inbound: coastal	reduced visibility	automatic update	yes
5	SF	inbound: coastal, harbor	clear/ day -night	automatic update	no
6	SF	inbound: coastal	clear/ day -night	manual/ conventional	no
7	SF	outbound: harbor, coastal	reduced visibility	automatic update	no
CONVENTIONAL BRIDGE/PAPER CHART					
8	NY	inbound: coastal, harbor	clear/ day -night	NA	NA
9	SF	inbound: coastal, harbor	clear/ day -night	NA	NA

The scenarios were designed to maintain the mariner's workload at a relatively high, but sustainable, level. A number of artificialities were introduced into the scenario procedures to achieve this level. Most notably, the mariner was alone on the bridge (with a helmsman) during conditions when, realistically, there would be at least one other officer. Additionally, most of the experimental transits went from the coastal confluence zone into harbor/pilotage waters without taking on a pilot. The expectation was that the high work-

load would increase the sensitivity of the performance measures to differences among scenario conditions. For example, with the high workload the mariner would presumably be forced to select what he felt to be the most effective method of navigation and, possibly, drop secondary tasks (e.g., bridge management tasks) not directly related to the ship's safety. If the workload were high enough, performance in the primary navigation and collision avoidance functions might also be degraded.

3.3.2 The Experimental Scenarios and the Mariner's Tasks

The design of nine unique but equivalent scenarios necessitated the development of a conceptual framework. First, the tasks and functions of the watchkeeper/conning officer in the coastal confluence and harbor/pilotage areas of operation were identified (Meurn, 1990; Crenshaw, 1975). These tasks and functions were then divided into three broad categories: navigation, collision avoidance and bridge management. The next step towards scenario design required consolidating the tasks and functions in each category into "generic" events that each represented an operationally logical unit. Table 3-2 shows the generic events which were used to construct all the scenarios.

Three parallel time lines of component events for navigation, collision avoidance and bridge management events where planned for each scenario. An experienced mariner then created the scenario data bases by placing approximately equal numbers of generic events from each category into each scenario to form operationally logical and realistic transits. Since the assessment of navigation workload and performance was the primary focus of the study and since collision avoidance was intrinsically related to safety and navigation, the intent was to keep navigation and collision avoidance relatively constant throughout a scenario and across all scenarios. The bridge management events/tasks were used to tune each scenario to maintain a consistently high workload during slow periods or to maintain equivalence when a particular scenario was intrinsically more or less difficult because of the nature of the route. The design of the experimental scenarios illustrates the type of control that is possible on a simulator, but impossible at sea.

The equivalence of the scenarios was examined by experienced mariners as a part of the preliminary testing during the experimental preparation. Revisions were made to some of the scenarios to increase equivalence before the principal data collection. During the data analysis, the scenarios were again examined for equivalency by comparing the mariners'

Table 3-2. Generic Events in the Development of the Experimental Scenarios

NAVIGATION	COLLISION AVOIDANCE	BRIDGE MANAGEMENT
- precision trackkeeping/ positioning	- own ship burdened, must give way	- non-time/location dependent routine task
- plan/calculate	- other vessel takes inappropriate action (or fails to take action)	- time/location dependent routine task
- alter course	- multi-ship encounter, ownship must act	- externally cued task
	- difficult to detect target	

workload ratings across scenarios. The scenarios did vary in navigation workload in ways that are attributable to the experimental manipulations. The navigation workload data are presented in Section 5. There were some unintended differences in collision avoidance workload that must be attributed to differences in the difficulty of the collision avoidance events. There were no differences among the scenarios in bridge management workload. These incidental data on collision avoidance and bridge management are presented in Appendix E.

3.4 INCLUSION OF THE PARTICIPATING MARINERS

The six participants for the study included four Masters (unlimited license), each with more than 20 years of experience, one Second Mate (two years of experience), and one Chief Mate (nine years of experience). They all had impressive resumes for their licenses and had simulator and/or computer experience. The intention was to select mariners who could be expected to adapt to the new technology and provide good performance and meaningful reactions in a very short time. The mariners' qualifications and experience are described in greater detail in Appendix C.

Each mariner spent a week at MSI/CAORF, becoming familiar with both ECDIS systems, making transits through all the experimental scenarios, and responding to extensive post-scenario and post-experiment questionnaires. The week's schedule for each mariner included the following events:

1. Training with the first ECDIS device (The "first" device was alternated for the six mariners.)
2. Familiarization with the bridge and all aspects of the experiment
3. Proficiency testing on the first ECDIS device
4. Experimental scenarios with the first device and one of the baseline scenarios, each followed by a post-scenario debriefing (The mariners ran through the scenarios in a different order so that position in the week did not bias performance in any one scenario.)
5. Training and proficiency testing with the second ECDIS device
6. The remaining experimental scenarios, each followed by a post-scenario debriefing
7. An extensive post-experimental debriefing

These events are described in greater detail in Appendix C.

4.0 PERFORMANCE MEASURES

Item 1 of the IMO Standards (International Maritime Organization, 1994) suggests that, compared to the conventional bridge, ECDIS should provide greater or equal safety and should reduce workload. In order to test these hypotheses, it was necessary to select performance measures to represent these abstract concepts. In addition, measures had to be selected to establish preferences for specific features and functions on the ECDIS systems. This section describes the selection of a variety of measures from a variety of sources.

4.1 SAFETY

The measurement of "safety" has been debated in shiphandling research for a long time. Generally, the solution has been to select a measure, or measures, of the mariner's ability to control the ship (Gynther, 1985; Kaufman, 1985; and Schryver, 1985). The most commonly used of these, cross-track distance from an intended track, seems especially appropriate for ECDIS with its emphasis on a geographical presentation of the navigation situation. In more recent years, the concept of "situational awareness" has moved from aviation (Sarter and Woods, 1991; Aretz, 1989; Schwartz, 1989) into shiphandling training and has been adapted by MSI/CAORF for use in its mariner training classes. Situational awareness was included here as a measure that is considered closer to the cognitive activity of the human operator than are ship tracks. A third measure based on the assumption that safety is related to performance was an experimenter's rating of errors.

4.1.1 Cross-track Distance from an Intended Track

A number of previous simulation studies (Smith, 1993; Smith and Mandler, 1992; O'Hara and Brown, 1985; Aranow, 1979) demonstrated improved trackkeeping, better execution of turns in narrows channels, and overall improved precision of navigation with the provision of ECDIS-like devices. These findings have been corroborated at sea (Gonin and Crowell, 1992; Cooper and Bertsche, 1981).

To perform the analysis, trajectory plots of each vessel's path were prepared and overlaid on a single plot for each scenario. The "composite track plot" for each scenario showed the planned trackline for the scenario, principal points of reference (buoys, channel lines, cultural features) and the actual route followed by each mariner that performed the scenario. A full set of these plots appears in Appendix E.

In the experiment reported here, there were no instructions for mariners to keep the ship close to the planned track as there had been in some earlier studies. They were permitted to set their own tolerance for distance as would be the case at sea. In addition, the scenario design required them to leave the planned track in response to frequent traffic encounters, some of them quite difficult. However, because of observed performance in the earlier studies, it was hypothesized that the precise information provided by ECDIS would encourage a small cross-track distance, even without instructions. To test this hypothesis, the ship tracks from the present experiment were examined for differences between ECDIS conditions and baseline conditions run with a conventionally equipped bridge without ECDIS. Special attention was given to critical points in the transits, such as approaches to major turns, precision anchoring maneuvers, and passage under bridges. At selected points in the transit, the mean cross-track distances from the intended tracks were calculated for both the ECDIS and conventional bridge conditions. To determine whether differences between the means of these conditions were reliable and meaningful a statistical procedure (the "t" test) was used. A summary table of the results of the these tests appears in Appendix E. Statistically significant (reliable) effects are discussed in Section 5.0.

4.1.2 Situational Awareness

Situational awareness is defined as the degree to which there is an accurate perception of the factors and conditions that are affecting the system (Sarter and Woods, 1991). The underlying premise here for trying to assess a mariner's level of situational awareness at any given time, is that there is a positive relationship between situational awareness and current level of navigational safety in the waterway. The hypothesis was that situational awareness would be greater with ECDIS on the bridge. Because there are no established techniques for measuring this phenomenon (although see Aretz, 1989), the experimental staff developed its own procedures for collection and analysis for the purposes of this experiment. The preliminary analysis suggested an effect in favor of the ECDIS conditions. Because there was only a suggestion of an effect, a decision was made not to invest further time in the analysis. The procedures that were used and the preliminary results are presented in Appendix D.

4.1.3 Experimenter's Ratings of Performance

In order to examine a broader range of performance and the "errors" that the mariners might make, performance during the experimental runs was rated by an observing mariner during each scenario. Structured rating scales were prepared by MSI/CAORF mariners, with separate lists of possible errors for the navigation, collision avoidance, and bridge management events that comprised a scenario. The hypothesis was that fewer errors would be committed in the ECDIS scenarios, at least for the navigation events. Because of the relatively exploratory nature of this measure and because of its minimal sensitivity to the experimental manipulations, formal analyses were not completed. The preliminary findings are presented in Appendix D.

4.2 WORKLOAD

Workload can be defined as the amount of work expected from an individual in a unit of time, using the resources available and its measurement is well established in human factors research (Lysaght et al., 1989). Implicit in the concept of ECDIS is the assumption that the introduction of an ECDIS, providing a real-time visual display of ship's position without the need for plotting, would improve safety by decreasing operator workload. The assumption is that safety would be increased because the watchstander will have additional time for situational evaluation and for keeping a lookout. A number of workload related measures were taken in an attempt to capture the workload experience.

4.2.1 Mariner Estimates of Time Spent Per Task Category

As mentioned in the discussion of scenario design in Section 3.3, the function of the bridge watchstander was conceptualized as comprising three categories of tasks: navigation, collision avoidance, and bridge management. In order to insure that mariners would be using a similar understanding of the kinds of activities that fall into each category, lists for each were compiled by mariners on the MSI/CAORF staff and confirmed by consultants. These lists appear in Appendix D. With these lists in front of them, the experimental mariners were asked to estimate the proportion of time they had spent performing tasks in each of the three categories during the transit just completed. Data obtained for ECDIS scenarios were compared to those obtained for non-ECDIS scenarios, and the results are presented in Section 5.0.

4.2.2 Mariner Ratings of Workload for Task Category

After a review of the literature, documented in Phase I of this study (MSI/CAORF Staff, 1991), the National Aeronautic and Space Administration's NASA Task Load Index (NASA-TLX) was selected as a measure expected to be sensitive to differences in experimental conditions and to be convenient to administer and to analyze (Hart and Staveland, 1988). The mariner's perception of workload for each scenario was assessed using this scale. After the mariner had estimated the proportion of time spent on navigation, collision avoidance, and bridge management-related tasks, he read a description of the six NASA-TLX workload dimensions, which include perceived levels of mental, physical and temporal demands, own performance, effort, and frustration. He rated his experience of workload during the transit on a zero to 100 point scale on each of the workload dimensions, thinking only about the navigation tasks. He then repeated the workload ratings procedure considering only the collision avoidance tasks, and then only the bridge management tasks. Each scenario produced three sets of workload ratings on each of the six scales. For each category of bridge task, the task-related workload score was computed, using a weighting procedure designed by the NASA developers. Sample data collection materials are presented in Appendix D.

Reliability of differences (statistical significance) among workload ratings was assessed by a Repeated Measures Analysis of Variance, a statistical procedure often used when measures are taken of the same individual on different occasions. In this case, each mariner provided ratings after each scenario. Additional statistical tests (single degree of freedom contrasts) were used to determine the reliability of very specific comparisons: for example, whether an ECDIS transit was superior to a conventional transit in the same harbor under the same scenario conditions. In selected cases, correlation between measures was also examined. The principal findings are discussed in Section 5.0, with some supplementary findings presented in Appendix E.

4.3 FEATURE AND FUNCTION USE

An additional issue central to the IMO standards, is the examination of which specific electronic chart features and ECDIS-based navigation functions are useful to the mariner. A major concern in this study was the usefulness of features during route monitoring. The data collected included direct observation of the mariners' ECDIS use during transits and their responses to detailed questionnaires. The various methods used to collect information on feature and function use, included:

1.) experimenter's tally of what was used during the transit
2.) the mariner's log of his use of the paper chart
3.) post-scenario questionnaires on features used or features needed but not available
4.) post-experiment questionnaire recording the mariner's recommendations on what should be available.

Supplementary descriptions of these procedures and sample materials are presented in Appendix D. A detailed presentation of the resulting data can be found in Section 6.0.

4.4 RADAR INTEGRATION

No additional performance measures were used to evaluate the contribution of radar integration to ECDIS. The measures described above were used to evaluate the effects of the radar integration on safety and workload and to examine the features used and preferred.

5.0 RESULTS AND DISCUSSION: CONTRIBUTION OF ECDIS TO SAFETY AND WORKLOAD IN ROUTE MONITORING

5.1 MARINERS' VIEWS OF ECDIS FOR ROUTE MONITORING

5.1.1 Mariners' Reports of the Primary Method Used for Navigation

To provide a context for performance in each experimental scenario, immediately after the scenario, the mariner was asked to report the primary method that he had used for navigation in each identifiable segment of the transit. The possible methods were paper chart, radar/ARPA, visual piloting, and ECDIS. Their reports are summarized in Table 5-1. The reports are divided into coastal and harbor/harbor approach phases (Federal Radionavigation Plan, 1992) with the change-over at the pilot station, on the assumption that the navigation problem changes at that point. The table shows the proportion of times that the mariner reported that a particular bridge "tool" was used as the primary navigation method during each bridge condition: the conventionally equipped bridge, ECDIS with automatic updating of position, and ECDIS without automatic updating of position.

Under the demanding experimental conditions, the one mariner alone on the bridge made use of time-consuming plotting on the paper chart only in the coastal phase of navigation and only with the conventionally equipped bridge. It is for this reason that this report refers to the baseline scenarios, not as the "paper chart" but more generally, as the "conventionally equipped bridge" or as "conventional methods." Radar use was reported for navigation with some frequency in all conditions, whatever the visibility and whether or not ECDIS was available. This use was in addition to its obvious use for collision avoidance. Presumably, this use of radar for navigation was a by-product of the need to refer to it frequently in all conditions for collision avoidance. Visual piloting was used in the harbor/harbor approach phase, as would be expected (Crenshaw, 1975), but not in the coastal phase. ECDIS with automatic positioning, when it was available, reduced the use of all other methods of navigation and became dominant. In the coastal phase, the difference between the radar and the available ECDIS was large and reliable (statistically significant, with $F = 23.23$, $p < 0.009$); in the harbor/harbor approach phase, the difference between the second-most-preferred-method, visual piloting, and ECDIS was

Table 5-1. Primary Method of Navigation as Reported by Mariners

BRIDGE CONDITIONS	PLOTTING/ PAPER CHART	RADAR/ ARPA	VISUAL PILOTING	ECDIS	TOTAL NUMBER SEGMENTS
	PROPORTION OF SEGMENTS USING EACH METHOD IN EACH BRIDGE CONDITION				
COASTAL PHASE OF NAVIGATION					
Conventional Bridge	0.43	0.57	0.00	NA	14
ECDIS Auto Positioning	**0.00**	**0.17**	**0.00**	**0.83**	**24**
ECDIS no Auto Positioning	0.29	0.71	0.00	0.00	7
HARBOR/HARBOR APPROACH PHASE OF NAVIGATION					
Conventional Bridge	0.03	0.25	0.73	NA	40
ECDIS Auto Positioning	**0.00**	**0.15**	**0.18**	**0.67**	**79**
ECDIS no Auto Positioning	0.05	0.61	0.28	0.05	18

also reliable or statistically significant ($F = 15.96$, $p < 0.02$). Alone on the bridge and with a high workload, the mariners preferred ECDIS as their method of navigation. ECDIS without automatic positioning was used very seldom as the primary method. With a failure of electronic positioning and with instructions to manually update the ship's DR position, the mariners frequently made use of the radar/ARPA to obtain a position and transferred that position to the ECDIS.

5.1.2 Mariners' Acceptance of ECDIS for Navigation

The comments made by the mariners during de-briefings provide an indication of how they saw the ECDIS contributing to, or inhibiting, their actions. The most commonly mentioned positive aspects of ECDIS use during high-stress events was that it provided quick and continuous confidence in own ship's position relative to charted objects such as channels and bridges. Many of the mariners mentioned that navigational workload was eased, allowing them to concentrate on collision avoidance. They also mentioned, however, that ECDIS did not help with collision avoidance during these events.

Among the more negative aspects of ECDIS use during high-stress events was a heightened attention to own ship's distance from the planned trackline that interfered on occasion with the task of watching for traffic. (There had been no explicit instructions to keep the ship close to that planned track.) This concern with the cross-track distance, which was obviously apparent on the ECDIS, resulted in a near miss with a another ship in a couple of cases, leading to increased anxiety. The mariners also lost confidence in ECDIS positioning on occasion, due to inconsistencies of object locations between the paper and electronic charts. (These electronic charts were not from National Oceanic and Atmospheric Administration, NOAA.) Finally, some mariners mentioned that at times they were not able to operate the ECDIS to obtain the information they required, causing them to revert to conventional methods of navigation when under pressure. Presumably, they felt that that was the most effective use of limited time.

5.2 CONTRIBUTION OF ECDIS TO THE SAFETY OF NAVIGATION

5.2.1 Effects of ECDIS on Cross-Track Distance from an Intended Track

Composite track plots, as described in Section 4.1, were examined for differences attributable to the presence or absence of ECDIS among the scenarios. A summary data table and a full set of composite track plots appear in Appendix E.

The participating mariners reported that when precision navigation was required, as in the harbor/pilotage regions, ECDIS was their primary method of navigation. Track plots of mariner/ship performance were examined for a decrease in cross-track distance with ECDIS. The most conspicuous examples are the greater precision found with ECDIS runs in San Francisco Harbor. Figure 5-1 compares Plot 5c (Scenario 5) and conventional

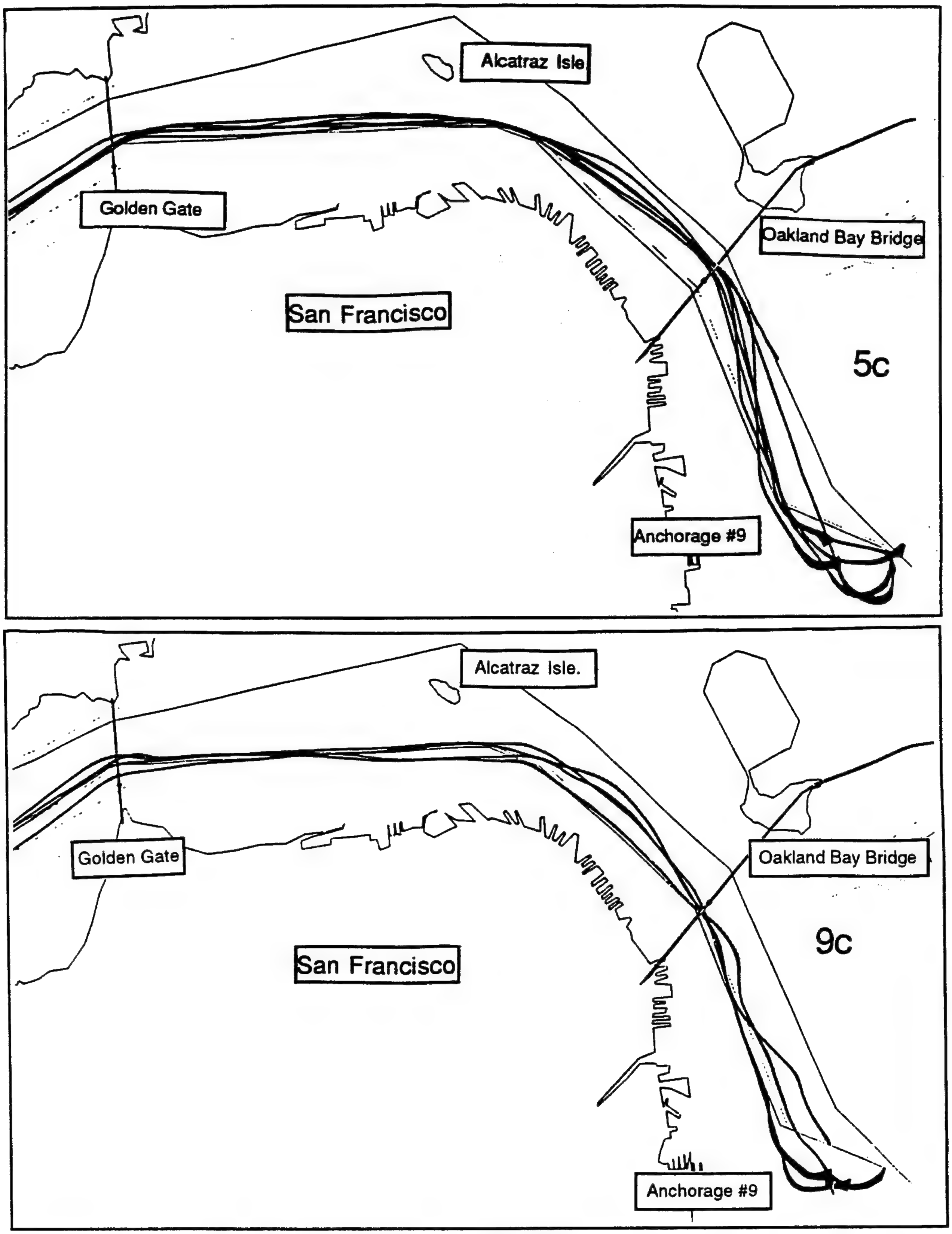


Figure 5-1. Composite Track Plots Using ECDIS (Scenario 5) and Using Conventional Bridge Procedures (Scenario 9)

bridge conditions in Plot 9c (Scenario 9). Significant mean cross-track distances were found there as summarized in Table 5-2. A similar trend of decreased cross-track distance with ECDIS was observed in New York Harbor, as illustrated in Appendix E in Plots 2b and 2c (Scenario 2) compared to Plots 8b and 8c (Scenario 8). Also apparent in the New York plots is a greater precision with ECDIS in the anchoring maneuver, although no statistical significance was found in the cross-track distances measured for the New York scenarios.

Table 5- 2. Mean Cross-Track Distance with and without ECDIS

LOCATION	MEAN CROSS-TRACK DISTANCE (METERS)		STATISTICAL SIGNIFICANCE
SAN FRANCISCO	**ECDIS Auto Position (Scenario 5)**	Conventional Bridge (Scenario 9)	
Golden Gate Bridge	**32**	117	0.05
Alcatraz 1st turn	**18**	100	0.09
Alcatraz 2nd turn	**29**	98	0.06

While mariners reported that ECDIS, when it was available, was also the primary method of navigation in the coastal region, trackkeeping performance in those scenarios showed no improvement over performance in the conventionally-equipped bridge scenarios. Presumably, there, the mariners considered it less critical to stay close to the planned trackline and did not take advantage of the accurate position information that ECDIS offered.

There was evidence, however, that using ECDIS, individual mariners made wide departures from the trackline in response to traffic or to avoid a developing traffic encounter. Figure 5-2 presents a striking example, showing that with ECDIS in Plot 2a (Scenario 2), there is an extreme excursion unlike any track made without ECDIS in Plot 8a (Scenario 8). Such departures with ECDIS can also be seen in Appendix E in Plot 5a (Scenario 5) as compared to the conventional condition in Plot 9a (Scenario 9). No statistical tests were done in the coastal regions because planned routes were different

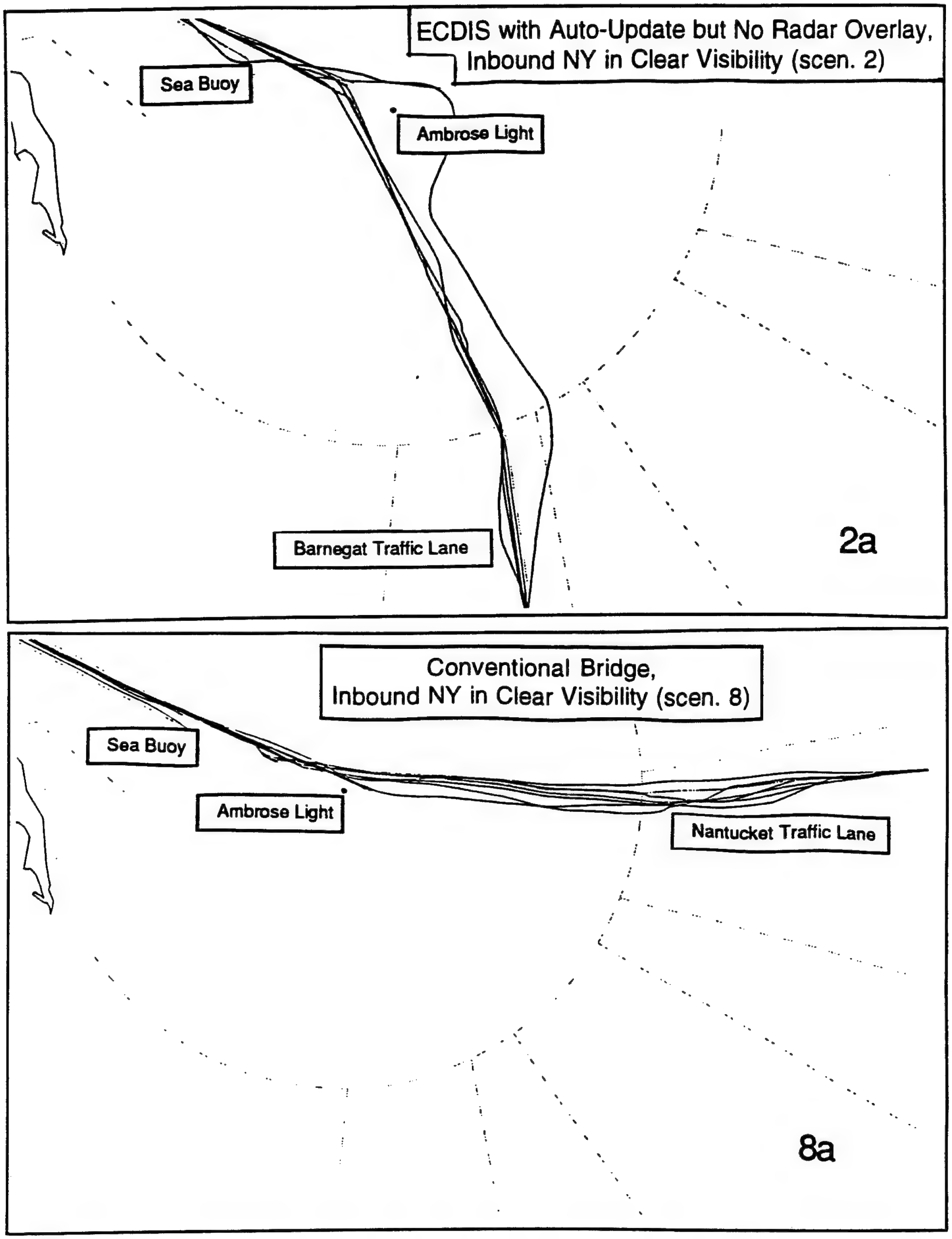


Figure 5-2. Composite Track Plots Using ECDIS (Scenario 2) and Using Conventional Bridge Procedures (Scenario 8)

between the scenarios (These differences had been designed to prevent the mariners from anticipating events from one transit to the next.). Such patterns of response to traffic were also seen in a previous study that found improved and more decisive collision avoidance maneuvers with addition of ECDIS-like capability to an ARPA (Hayes, 1979).

5.3 EFFECT OF ECDIS ON THE WORKLOAD OF THE TRANSIT

5.3.1 Effect of Navigation Workload on the Distribution of Time as Reported by the Mariners

After each scenario the mariners were asked to rate their perceived workload, using the NASA Task Load Index (NASA-TLX) described in Section 4.2. Separate ratings were given for navigation, collision avoidance, and bridge management tasks. The mean workload rating for navigation is presented in Table 5-3. Table 5-3 shows that the availability of ECDIS with automatic positioning decreased navigation workload from conventional procedures and that attempts to use ECDIS without automatic positioning increased workload. These differences in workload were statistically different ($F = 24.69$, $p < 0.006$ and $F = 41.89$, $p < 0.002$, respectively). The use of ECDIS without auto-positioning is discussed further in Section 5.4.

To explore further the nature of mariner's workload, distribution of time was also examined. After each scenario the mariners were asked to estimate the proportion of total time spent on each category of activity: navigation, collision avoidance, and bridge management. The means of reported proportions are summarized in Table 5-3. Statistical tests showed that the decrease in proportion of time spent on navigation from the conventional bridge to ECDIS with automatic positioning was significant ($F = 5.61$, $p < 0.06$). The corresponding increase in proportion of time spent on collision avoidance with ECDIS with automatic positioning was also significant ($F = 5.04$, $p < 0.07$). Differences between the ECDIS with no automatic positioning and the other bridge conditions were not statistically significant. This reciprocal relation between the proportions of time spent on navigation and on collision avoidance is illustrated in Figure 5-3.

Table 5-3. Navigation Workload and Reported Distribution of Mariner's Time

BRIDGE CONDITIONS	MEAN NAVIGATION WORKLOAD	MEAN PROPORTION OF TIME ON TASK IN EACH BRIDGE CONDITION		
		NAVIGATION	COLLISION AVOIDANCE	BRIDGE MANAGEMENT
Conventional Bridge	52	0.46	0.33	0.21
ECDIS Auto Positioning	**36**	**0.37**	**0.41**	**0.21**
ECDIS no Auto Positioning	63	0.49	0.34	0.17

Note: Proportions that do not total to 1.0 are the result of rounding error.

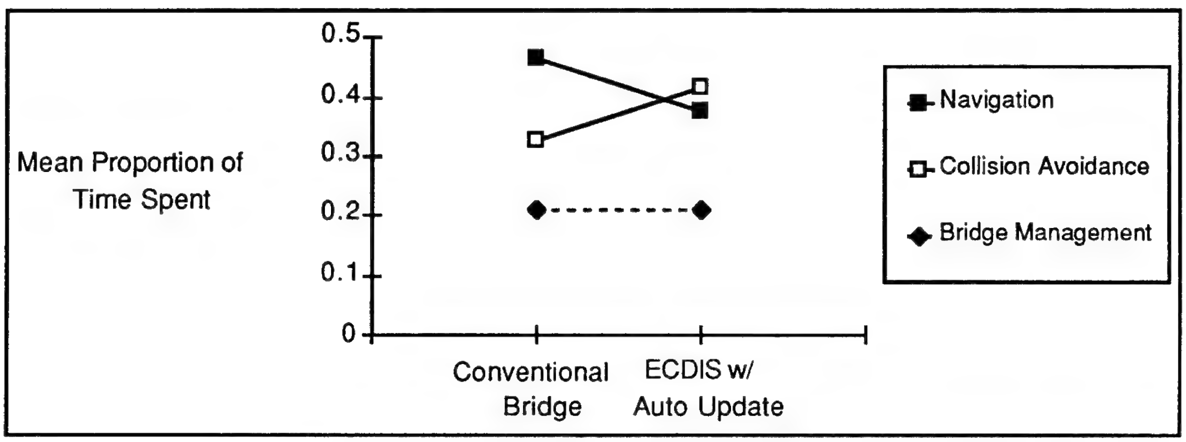


Figure 5-3. Mean proportion of time spent on bridge tasks during conventional bridge scenarios versus ECDIS scenarios

Note that the proportion of time spent on bridge management tasks, as reported in Table 5-3, does not appear to be affected by the presence or absence of an ECDIS on the bridge. This finding is consistent with comments made by some of the mariners that having an ECDIS on board as a navigation device does not really reduce or make easier the bridge management-related tasks. That is, the mariners still had to fill out communications log sheets, make bell book entries, perform and record gear tests, etc.

Since the addition of ECDIS with automatic positioning to the bridge was observed to affect two performance measures -- the perceived mariner workload and the proportion of time spent on a category of task -- correlations between them were examined. Workload for navigation and the proportion of time spent on navigation were positively and significantly correlated ($r = 0.51$, $p < 0.002$). Decreased workload for navigation was associated with decreased proportion of time spent in navigation. Decreased workload for navigation was also correlated with an <u>increase</u> in the proportion of time spent on the collision avoidance task ($r = -0.575$, $p < 0.002$). To summarize the findings, ECDIS with automatic positioning was associated with a decreased workload for navigation, a decreased proportion of time spent on navigation, and an increased proportion of time spent on the collision avoidance task.

An implicit hypothesis underlying Item 1 of the IMO standards (International Maritime Organization, 1994) is that there is a relation between decreased workload and increased safety. These findings support such a relation and suggest a mechanism. With the introduction of ECDIS to the bridge the mariner is relieved of the necessity of manually fixing his position every few minutes, and thereby has more time to spend on other tasks. The mariners in this experiment spent the savings in time on "look out" and on the collision avoidance task. This extra attention to collision avoidance suggests a potentially greater level of safety in the waterway when an ECDIS is on board.

5.3.2 Perceived Workload for Navigation, Collision Avoidance, and Bridge Management

After each scenario the mariner was asked to rate separately his experience of navigation, collision avoidance, and bridge management workload, using the NASA-TLX workload measurement technique described in Section 4.2. Overall, this technique worked well in discriminating among perceived workload levels produced by the different scenarios.

The mean navigation, collision avoidance, and bridge management workload scores are plotted in Figure 5-4 for the conventional bridge scenarios as compared to the ECDIS-with-automatic-positioning scenarios. As can be seen, the reduction in perceived navigation workload as a result of the availability of ECDIS is substantial. An analysis of variance on these data and a subsequent single degree of freedom contrast show that the difference in mean workload for navigation is highly significant ($F = 24.69$, $p < 0.006$). The collision avoidance effect shown here is also significant, as an artifact of differences among

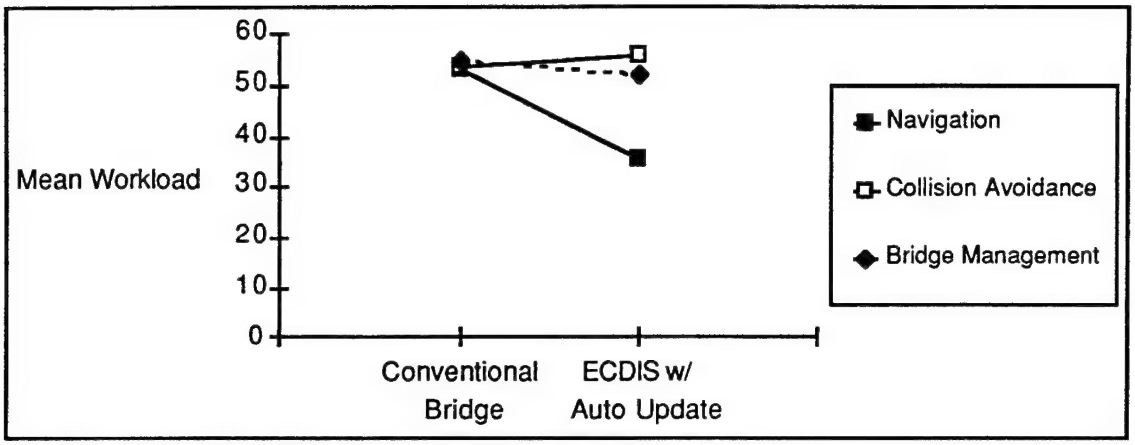


Figure 5-4. Mean workload for navigation, collision avoidance, and bridge management tasks during conventional-bridge (Sc 8 & 9) versus ECDIS scenarios (Sc 1, 2, 4, 5, & 7) scenarios.

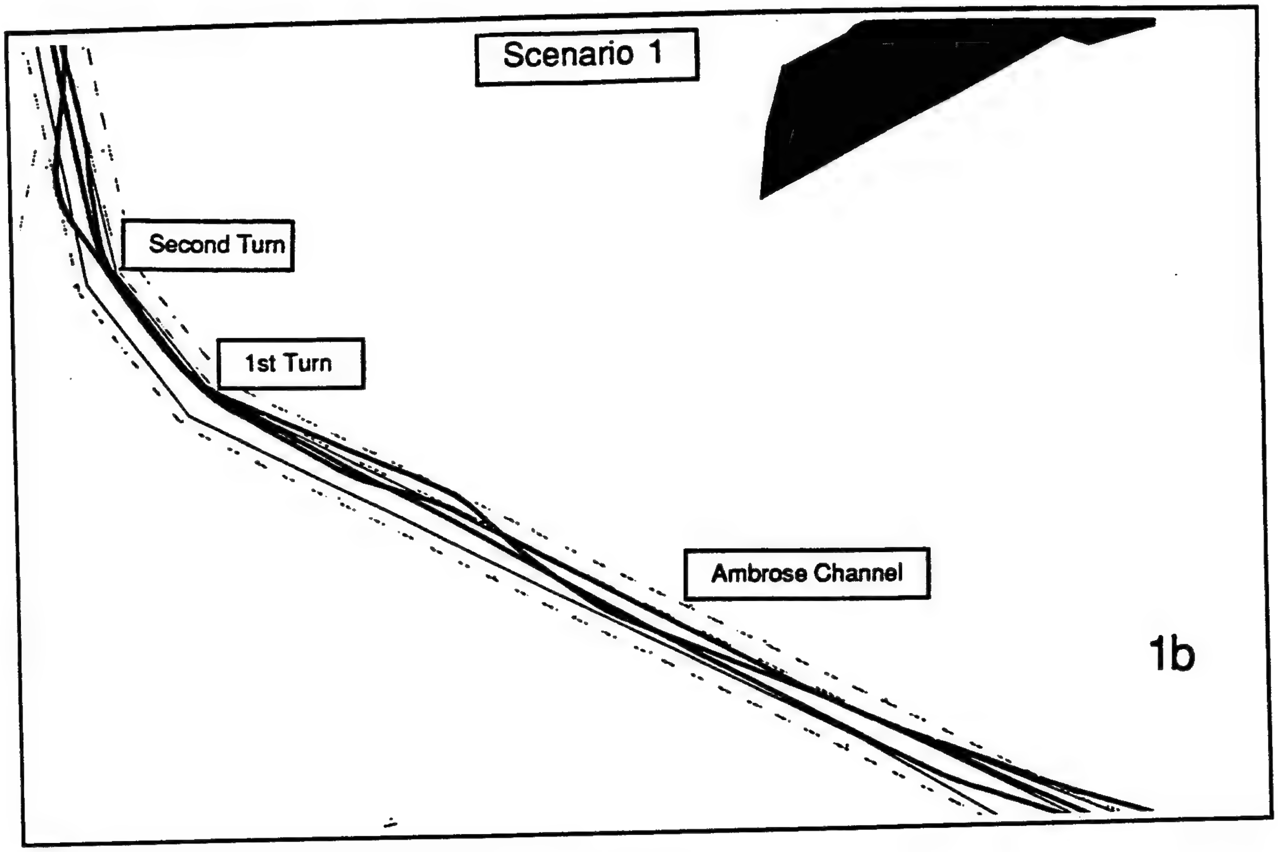
The bridge management effects is not significant. Further analyses of the workload data are presented in Appendix E.

5.4 EFFECTS OF USING ECDIS WITH A LOSS OF AUTOMATIC POSITIONING

5.4.1. Effects of Loss of Automatic Positioning on the Cross-Track Distance

The mariners experienced each of the two ECDIS devices without their automatic DGPS positioning feature and with instructions to manually update the DR position. The track plots were examined for the possible effects on cross-track distance. Generally, this measure was not affected in the coastal regions. However, it was affected in the harbor/pilotage regions. Comparisons were made between ECDIS in the auto-update mode (Scenarios 1 and 5) and ECDIS in the manual update mode (Scenarios 3 and 6). The most extreme effect is in the comparison between New York Scenarios 1 and 3 illustrated in Plots 1b and 3b, in Figure 5-5. The figure shows that, while trajectories in Ambrose Channel meander about the planned trackline in both scenarios, trajectories are much tighter around the first and second turns when ECDIS is automatically updating the position of own ship (Scenario 1). The mean cross-track distances in the turns are summarized in Table 5-4. T-tests on these data show significant differences at the first turn ($t = 2.925$, $p < 0.09$) and the second turn ($t = 12.39$, $p < 0.006$).

Comparisons between San Francisco Scenarios 6 and 5, illustrated in Appendix E, show a similar effect. With automatic updating, trajectories clustered more tightly around the



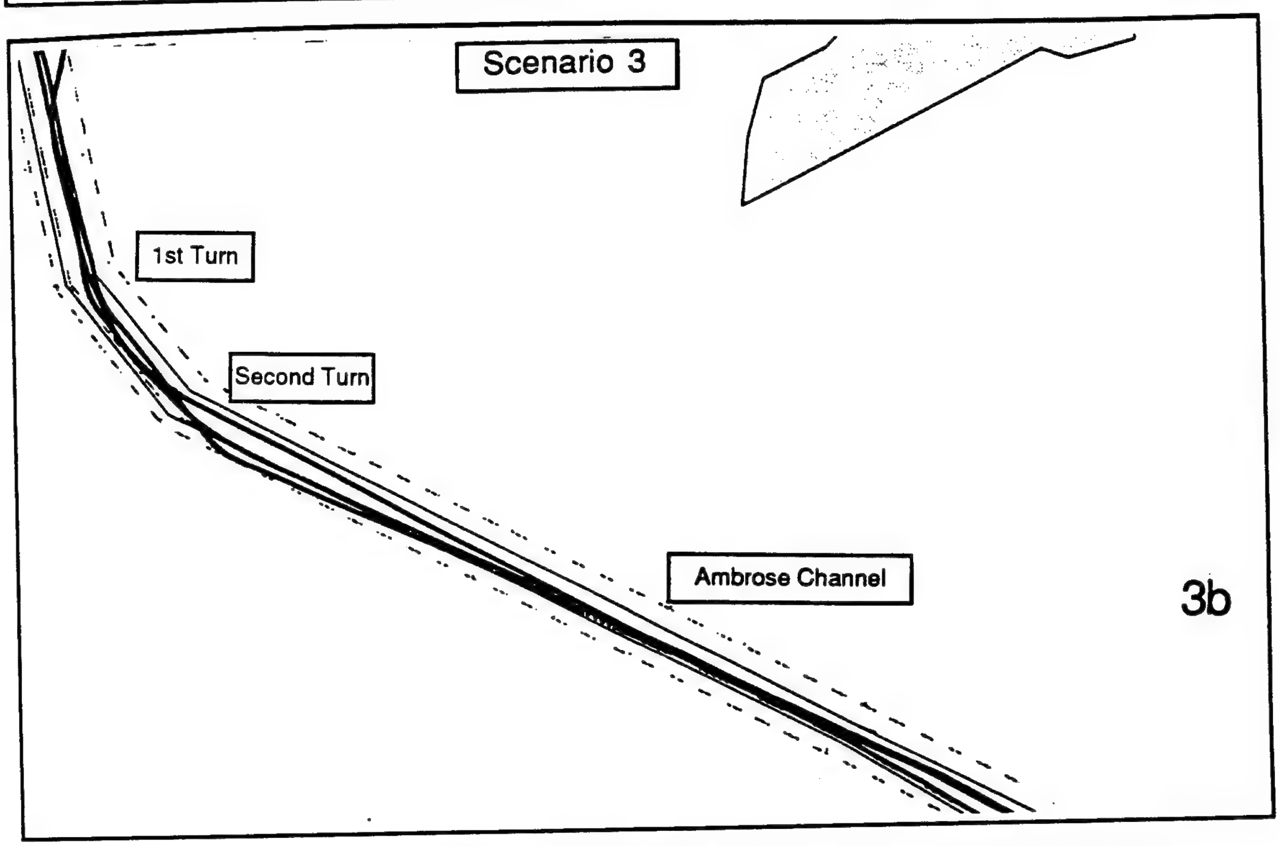


Figure 5-5. Composite Track Plots Using ECDIS with Automatic Positioning (Scenario 1) and Using ECDIS with Manual Updating (Scenario 3)

Table 5-4. Mean Cross-Track Distance with and without Automatic Updating of Position

LOCATION	MEAN CROSS-TRACK DISTANCE (METERS)		PROBABILITY
NEW YORK	**ECDIS Auto Position (Scenario 1)**	ECDIS No Auto (Scenario 3)	
Ambrose 1st turn	**41**	128	0.09
Ambrose 2nd turn	**59**	219	0.006
Verrazano Bridge	**18**	148	0.18

planned trackline, both at the entrance to San Francisco Channel and through the Channel to the Golden Gate Bridge. However, differences at these points were not statistically significant.

During the test runs, the mariners were frequently observed to abandon the manual updating of ECDIS opting instead for conventional procedures, apparently feeling they could not safely navigate with ECDIS in this mode. To determine whether this objective measure of safety, cross-track distance, verified their judgment, trackkeeping performance using ECDIS in the manual update mode was compared to that using conventional bridge procedures. Trackkeeping performance in coastal regions was not different between these two conditions. However, trackkeeping performance in the harbor/pilotage regions was poorer, when using ECDIS with manual updating of position, than that observed in the baseline conventional navigation scenarios.

Performance with manual updating in New York Scenario 3, illustrated in Plot 3b of Figure 5-5, shows that the trajectories were clustered more loosely around both turns in Ambrose Channel than was the case in the comparable conventional bridge Scenario 8, illustrated in Plot 8b in Figure 5-6. Mariners were consistently further off-track when manually updating their position with ECDIS than with conventional navigation. T-tests performed on the cross-track data showed a trend toward such a difference, at both the first turn in Ambrose Channel ($t = 2.053$, $p < 0.17$) and the second turn ($t = 2.176$, $p < 0.16$). A similar pattern

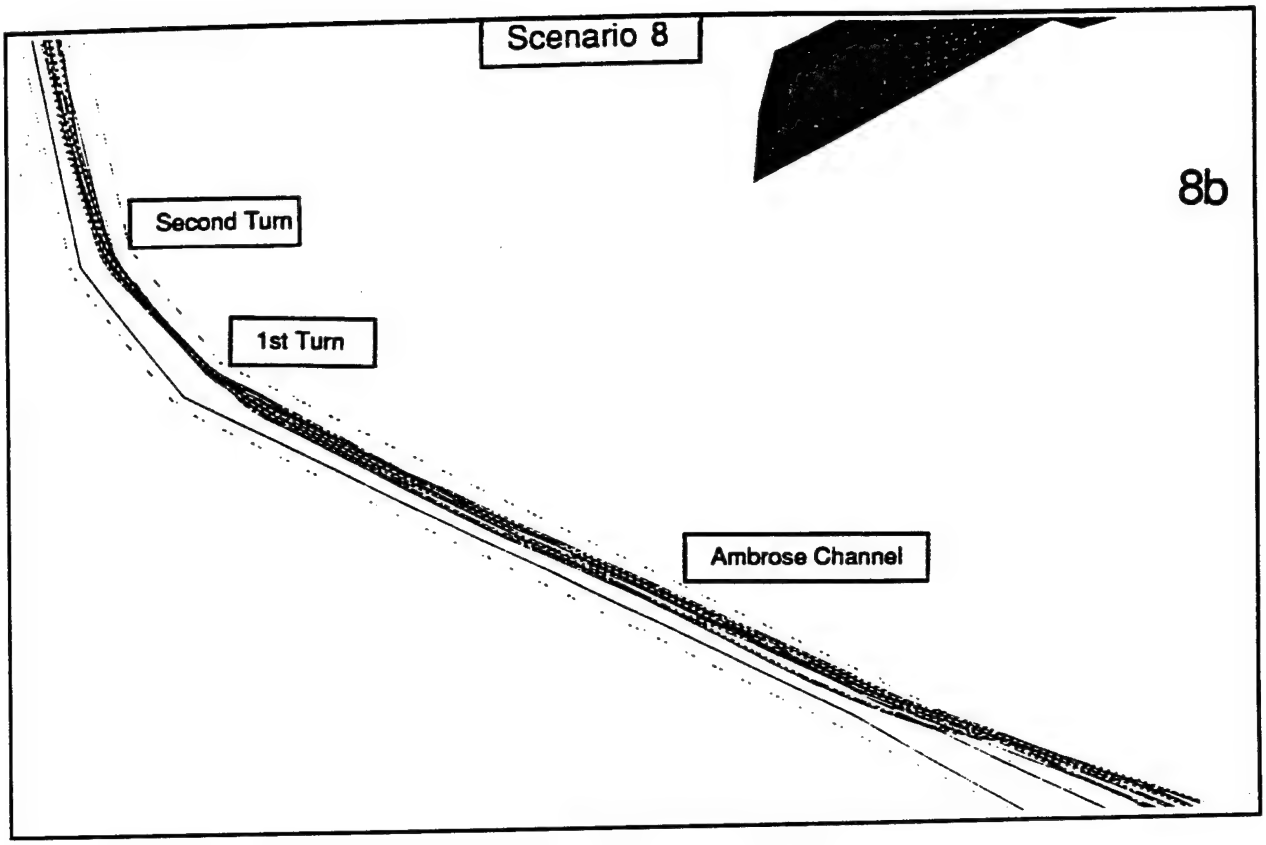


Figure 5-6. Composite Track Plots Using Conventional Bridge Procedures (Scenario 8)

was observed in the track plots for corresponding San Francisco Scenarios 6 and 9 which appear in Appendix E. Mariners reported they had greater difficulty making the turn around the San Francisco Buoy (Plot 6a) when manually updating ECDIS. However, t-tests revealed no significant differences in cross-track distance between this scenario and conventional navigation in Scenario 9. Overall, cross-track distances suffered in the manual update scenarios.

5.4.2 Effects of Loss of Automatic Positioning on the Mariners' Workload

Figure 5-7 shows the mean proportion of time spent on navigation-related tasks during the OSL and Robertson manual update scenarios (Scenarios 3 and 6, respectively) as compared to each device in its normal operating mode (Scenarios 1 and 5). The increase in the proportion of time spent on navigation is large, especially for the OSL device.

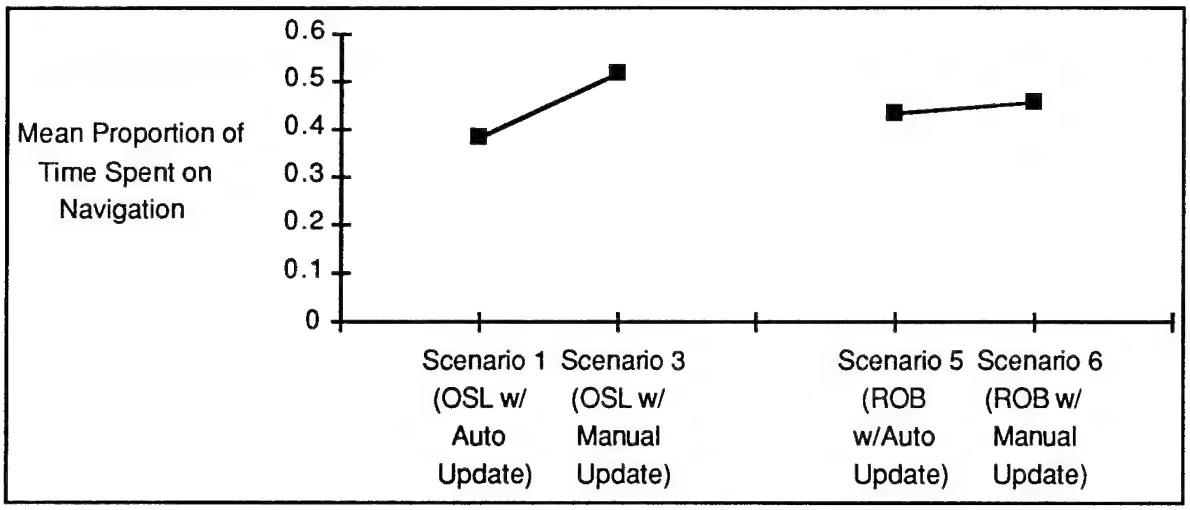


Figure 5-7. Mean proportion of time spent on navigation with automatic versus manual updating of position

Figure 5-8 shows the mean navigation workload for the scenarios with automatic updating of position compared to those without it (Scenarios 1 versus 3 and 5 versus 6). Navigation workload was dramatically increased when the mariner was required to manually update his position on the ECDIS, as compared to when the ECDIS had automatic DGPS positioning. The increase in mean navigation workload was statistically significant comparing Scenarios 1 and 3 ($F = 20.70$, $p < 0.008$) and comparing Scenarios 5 and 6 ($F = 21.20$, $p < 0.008$).

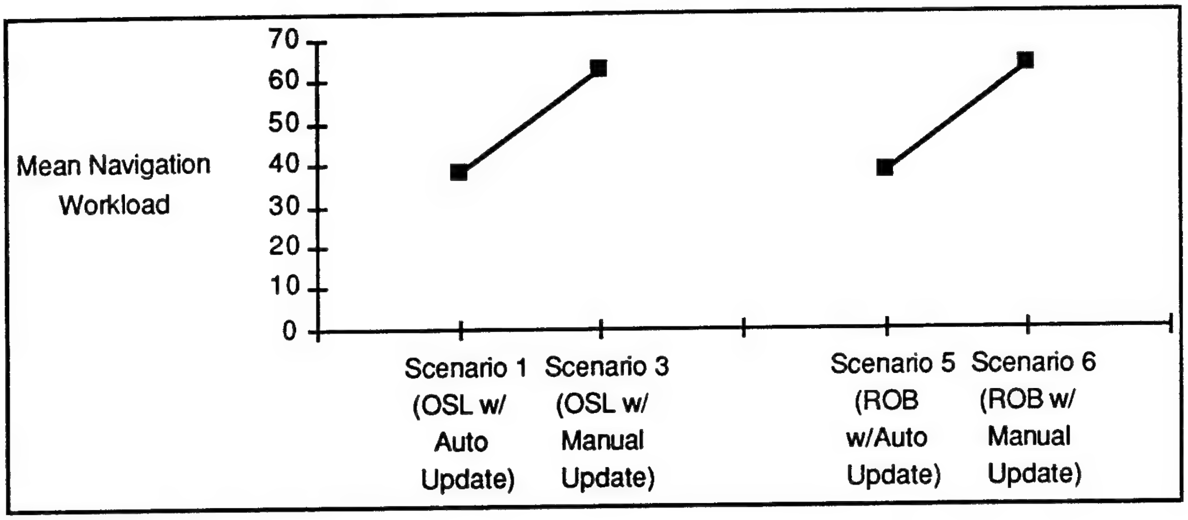


Figure 5-8. Mean navigation workload with automatic versus manual updating of position

The routes for these transits are illustrated in Appendix E, in the composite track plots. Note that the transit routes being compared in Figures 5-7 and 5-8 are not of equal length. While Scenarios 1 and 3 were both New York transits in reduced visibility, Scenario 3 was outbound and only ran from Stapleton anchorage to the pilot station. Scenario 1, on the other hand, ran all the way from the coast into Stapleton Anchorage - a much longer transit. The difference in mean navigation workload is even more impressive considering the extra distance transited in Scenario 1, suggesting that the manual updating of the ECDIS may have affected the navigation workload substantially. A similar argument could be made comparing the transit routes for Scenarios 5 and 6. Both were San Francisco transits in clear visibility, but Scenario 5 went all the way from the coast into Anchorage 9 while Scenario 6, the manual update scenario, stopped at the Golden Gate Bridge.

The conventional bridge transits (made without an ECDIS) discussed in Section 5.2.1 above were also relatively long transits, extending from the coast all the way to Stapleton Anchorage (Scenario 8) or Anchorage 9 (Scenario 9). Even so, the mean navigation workload was perceived to be greater in the manual update scenarios than for the conventional bridge scenarios (Scenarios 3 vs. 8: $F = 5.77$, $p < 0.06$; Scenarios 6 vs. 9: $F = 2.66$, $p < 0.12$). To summarize, ECDIS without automatic updating of position, and the requirement to manually update the position, resulted in a significantly higher workload than either ECDIS with automatic positioning or conventional procedures.

The extremely negative view of ECDIS without automatic updating of position should be qualified, however: there was only one mariner on the bridge with other responsibilities, the mariners were instructed to update the position on ECDIS in pilotage waters where they ordinarily would not be alone on the bridge plotting on the paper chart, both of the ECDIS systems used were prototypes with relatively tedious procedures for manually updating, and these mariners had relatively little experience with the systems. Under some circumstances, manual updating might be more effective than it was seen to be here.

6.0 RESULTS AND DISCUSSION: ROLE OF ECDIS FEATURES IN ROUTE MONITORING

This section presents the role of the chart features and navigation functions that were available on the ECDIS systems. The characteristics of the Robertson and Offshore Systems Limited (OSL) systems are described briefly in Section 2.2 and in greater detail in Appendix B. The methods of data collection are described in Section 4.3 and in Appendix D. Also reported in this section are the additions or modifications that these mariners, given their simulator experience navigating with ECDIS, would have liked to have seen and their views on what information should be permanently or optionally displayed. Remember that the mariners experienced the systems only for route monitoring. Their preferences may have been different for route planning.

6.1 OBSERVATIONS ON THE NEED FOR DISPLAY ACCURACY

Earlier research (Smith and Mandler, 1992) has shown that a high level of display accuracy is necessary for safety of navigation and for mariner confidence. Therefore, the experimenters were very sensitive to the accuracy of the displayed information. First, a variety of problems were found with the digitizing accuracy of the electronic charts received from the vendors of the two commercial ECDIS systems used. This was especially true with electronic charts digitized from small scale paper charts. These errors -- in one case a buoy was 250 feet out of place -- had major effects on the mariner's trust in the systems and have obvious implications for safety of navigation. These observations support a conclusion that electronic charts must be based on electronic navigation charts (ENCs) developed by national hydrographic offices in conformity with international standards. Certainly, the possibility that ECDIS systems would enable mariners to digitize their own charts should be approached with great caution.

The simulator data bases were modeled with the high levels of accuracy that are characteristic of DGPS for several reasons including: the requirement in the Federal Radionavigation Plan (Federal Radionavigation Plan, 1992) of a high level of positioning accuracy for the harbor/harbor approach phase of navigation, earlier research that supported a need for highly accurate positioning for piloting in restricted waterways (Smith and Mandler, 1992; Gynther and Smith, 1989), and the present availability of DGPS. The observed concern of the mariners with the accuracy and credibility of the display suggests that ECDIS should be used in the harbor/harbor approach phases of navigation only with high levels of positioning

accuracy (whether that accuracy is achieved using DGPS or some other means).. Participating mariners pointed out that, in other circumstances, ECDIS would be a useful addition to the bridge as long as the navigator can achieve positioning accuracy equal to or better than that currently available to him with conventional methods, with equal or less effort than currently required.

The mariners' concern for display accuracy included the scaled ship image presented on larger chart scales. One of the devices presented a scaled image at the larger chart scales; the other presented a ship image that was not scaled for the dimensions of own ship or for the chart scale. There was a strong preference for the accurately scaled outline. This preference is consistent with earlier findings of the best performance and confidence for piloting in restricted waterways with a scaled ship image against channel outlines (Smith, 1993; Smith and Mandler, 1992; Gynther and Smith, 1989). Indeed, in one study (Smith, 1993) marine pilots suggested a scaled outline for traffic ships to be met in narrow channels.

6.2 USE OF ELECTRONIC CHART SCALES

One of the most frequently-observed mariner actions was the changing of chart scales. The two systems differed both in the size of the chart display and in their treatment of chart scales and, therefore, need to be described separately. The Robertson system had a dedicated 63.5-centimeter (cm) (25-inch) screen with horizontal and vertical dimensions of 52.83 cm by 35.31 cm (20.8 inches by 13.9 inches). The chart scales were labeled, as they are for paper charts, as 1: 20,000, etc. The scales that were chosen through the menus are listed in the first column in Figure 6-1. The second column in the figure indicates the size of the geographic area that was visible on the single Robertson screen for those scales that were most frequently chosen by the mariners. The frequencies with which each chart scale was chosen is presented in the third column. In general, the mariners tended to "experiment" with the chart at different scales (accounting for the low frequencies for many of the chart scales) but usually came back to the preferred scales indicated by the higher frequencies. For the Robertson system, the most preferred scales were 1: 20,000, 1: 50,000, and 1:100,000, the harbor and coastal scales that were most familiar from paper chart use.

The OSL system had a 48.26-cm (19-inch) screen that could be configured to display a number of windows. The most frequently used configuration had a larger, main chart to the

Robertson			OSL			
Chart Scales	Geographic Area (nm)	times chosen	Chart Radius (nm)	Geographic Area (nm)	Main Chart (times chosen)	Second Chart (times chosen)
			1/8		0	5
			1/4		0	7
			1/2		5	4
			3/4		1	4
			1		5	5
1: 20,000	5.71 x 3.81	20		2.89 x 2.89		
1: 25,000		4	1 1/2		7	1
1: 30,000		12	2		9	1
1: 35,000		2	2 1/2		6	2
1: 40,000		10	3		17	3
1: 50,000	14.26 x 9.53	27		7.23 x 7.23		
1: 60,000		2	4 1/2		11	0
1: 70,000		6	6		11	5
1: 75,000		1				
1: 80,000		12				
1: 100,000	28.52 x 19.06	20		14.45 x 14.45		
1: 110,000		2	8		5	3
1: 120,000		4	12		5	4
1: 125,000		1	24		1	2
1: 130,000		3	50		0	0
1: 150,000		6	100		0	0
1: 160,000		1				
1: 180,000		1				
1: 240,000		1				
1: 500,000		1				
total chart scale changes		136	total chart scale changes		83	46

Figure 6-1. Tallies of the Frequency of Chart Scale Selection

left and a smaller, second chart in the upper right hand corner. With this configuration, the main chart was 26.67 cm square.(10.5 by 10.5 inches), showing a smaller area for a comparable scale than that shown on the Robertson system. The OSL chart scales were labeled as one half the vertical or horizontal dimension of the chart, a specification analogous to the radius of a radar image, as 1 nautical mile (nm), etc. The available scales are listed in the fourth column of Figure 6-1. The fifth column shows the geographic areas that would be visible on the main chart of the OSL at scales that would correspond to those most frequently chosen on the Robertson.

The most frequently chosen OSL scales, in the sixth column of the figure tend to cluster around those most frequently chosen on the Robertson. This tendency suggests that the mariners had a preference for familiar chart scales.

When using the OSL ECDIS, mariners indicated that having two chart windows on the display was quite useful. Some of the mariners preferred to keep the smaller, secondary chart at a relatively small scale, so that at a glance they could see a larger portion of the area covered by the digitized chart than that shown on the main chart. The mariners' use of this arrangement was chosen with some frequency, as indicated in the last column of the figure. Some of the mariners found a different use for the second chart: they used a very large scale (smaller radius) that showed only the planned track and the scaled outline of own ship. This arrangement is a graphic presentation of the cross-track distance indicated in the alphanumeric display. It could be considered an approximation to a steering display, rather than a navigation display. The relatively high frequencies for the small radius scales are the result of only a few mariners making that selection a number of times. In general, changes in scale of the secondary chart were made depending on location in the waterway.

6.3 USE OF ELECTRONIC CHART FEATURES

A consideration in the selection of the two ECDIS systems was the differences in the presentations and content of their electronic charts. The <u>Robertson</u> electronic chart was more complex and more closely imitated a paper chart. Its permanently retained features included the coastline, several pre-defined depth contours, traffic routing systems, and an indication of the selected scale (the latter as part of the separate LCD panel). In addition, six independent layers of chart data could be added including buoy symbols, depth soundings, a latitude/longitude grid with scale bar, two levels of text (major place names, and minor place names with aids to navigation characteristics), indication of lighted aids, and indication of submerged wrecks and other hazards.

The permanently retained features of the simpler <u>OSL</u> electronic charts included the coastline, several pre-defined depth contours, and an indication of the selected scale (the latter as a part of the separate touch screen panel). Other features that could be added to the display included buoy symbols, compass rose, north arrow, and a visible bearing line. The characteristics of the two ECDIS systems are described more completely in Appendix B.
Data collection methods used to examine the mariners' use of, and reactions to, the electronic chart presentations included:

1.) an experimenter's tally (via remote video camera) of the chart features enabled/dis-enabled

2.) the post-scenario questionnaire in which the mariner selected features used from a list of those available and added other features desired

3.) the paper chart use form on which the mariner recorded any information used

4.) the post-experiment questionnaire in which the mariner gave his opinion on whether to display various chart features "always," "at the users option," or "never"

6.3.1 Experimenter's Tally of Electronic Chart Features Used

Table 6-1 shows the chart features that could be manipulated on each ECDIS system and the frequency with which each was enabled/dis-enabled for the Robertson and OSL ECDIS scenarios. For the four scenarios using the Robertson ECDIS, the mariners kept the beacons, buoys, danger symbols, and the main level of text displayed most of the time. Mariners tended to enable both the second level of text and the depth soundings to read the information and then immediately dis-enable them. Many mariners enabled the latitude/longitude grid only when they reached the channel. The relatively high frequencies shown in the table for the Robertson depth soundings, text, and grid tallies were accumulated as a result of one mariner's attempt to orient himself during the manual update scenario, contributing 23, 12, and 12 tally points to those three features, respectively. Otherwise, each feature was turned on or off only one to five times per scenario.

For the three scenarios using the OSL ECDIS, mariners always kept the buoy symbols enabled, although this might have been because a rather complicated procedure was involved to enable/dis-enable them. The compass rose and north arrow were generally kept enabled, though the mariners tended to enable/dis-enable the visible bearing line between one and five times per scenario.

6.3.2 Post-Scenario Questionnaire on Electronic Chart Features Used

The post-scenario questionnaire presented a list of features and asked the mariner to indicate which features he had actually used. For the most part, the mariners all indicated that they used the traffic lanes, buoy symbols, light characteristics and depth markings during each of the four Robertson scenarios. In only about one-third of the transits did the mariners indicate that they used the danger markings, geographic names, grid, and aids to navigation characteristics.

Table 6-1. Observed Use of Electronic Chart Features

Robertson Chart Feature	# times turned on/off		OSL Chart Feature	# times turned on/off
Beacons	37		Compass rose	4
Buoy Symbols	41		North arrow	4
Danger Symbols(Marks)	46		Visible bearing line	11
Depth Soundings	71		Change chart layout	3
Text	67			
Grid	45			

The additional chart features mariners most commonly indicated that they would have wanted on the ECDIS include buoy names and numbers, information on bridges and anchorage locations, numerical indication of the depths associated with the contours, and the names of strategic geographic points. See Table E-3 in Appendix E for a complete list of the features mentioned by each mariner. Note that Table E-3 also itemizes the information each mariner took from the paper chart discussed in Section 6.3.3 below as well as additional navigational data required as discussed in Section 6.4.2.

6.3.3 Paper Chart Information Used

During the ECDIS scenarios, the relevant paper charts (on which a passage plan had been prepared by the experimental staff) were available if necessary. The mariners were asked to record any information they took from the paper chart during the scenario on a "paper chart use" form.

By far, the most predominant use of the paper chart was to reference the buoy numbers in Ambrose and San Francisco channels. Buoy names and points of land used for taking fixes were also referenced fairly often, as were depth soundings (for comparison to Robertson soundings) and occasional position plotting to confirm the vessel's location. Indeed, several mariners mentioned that buoy names and numbers must be accessible for reference during ship-to-ship and ship-to-shore communications. Mariners also mentioned that while some text was available on the Robertson ECDIS, more consideration must be given to choosing, from the mariner's perspective, the most useful points of land, etc. to label.

6.3.4 Post-Experiment Questionnaire on Display of Chart Features

The mariners were asked to give their recommendation on *when* the ECDIS should display each of the chart features listed in Table 6-2. Table 6-2 shows the number of mariners (out of six) who indicated that each feature: should be displayed *always*, should be turned on or off with a single keystroke at the *users option*, or should *never* be displayed. The table has been re-organized here to highlight the areas of consensus among the mariners who participated in the study.

The mariners were also asked to choose the three *most* important and three *least* important features for an electronic chart, from the list given in Table 6-2. Table 6-3 presents those features chosen by the mariners. Note that there is some consensus about which are *most* important.

6.4 ECDIS-BASED NAVIGATION FUNCTIONS

The Robertson ECDIS provided a variety of navigational data and functions including course, speed, course and speed made good, set, drift, vessel and cursor lat/long, and range/bearing to the cursor. Data available on selected ARPA targets (one at a time) included range/bearing, CPA and TCPA. When the "automated navigation tracking system" was enabled, data were available including cross-track error, course to steer, distance to go, rate of turn, and ETA, along with a variety of warning alarms. Other navigational data were also available including true or relative heading/speed vectors for targets and own ship, dead reckoning position reset, track history with or without time labels, and a mechanism for numerically inputting own ship's course, speed, set and drift.

The OSL ECDIS also provided a variety of navigational data and functions including vessel and cursor lat/long, gyro, range/bearing to the cursor and to up to four targets, cross-track error, course to steer, a position offset function for manual positioning, and a full radar overlay with gain control.

Table 6-2. Mariners' Recommendations of Charted Features

CHARTED FEATURES	Display Always	At Users Option	Display Never
	(# of mariners)		
coastline/landmass	6	0	0
indication of fixed aids to navigation	6	0	0
indication of floating aids to navigation	6	0	0
Federal channel lines	4	2	0
navigation lanes/fairways	4	2	0
pilot areas	4	2	0
indication of isolated dangers	4	2	0
spot soundings	0	6	0
names-landmasses, islands, points,etc.	1	5	0
light / sound characteristics	1	5	0
cable/pipeline areas	1	5	0
details of isolated dangers	1	5	0
Lat/Long grid lines	1	5	0
bottom characteristics	0	5	1
details of cautionary notes	0	5	1
ENC edition date	0	5	0
anchorages	2	4	0
bottom contours	2	4	0
compass rose	2	4	0
physical classification (can/nun)	1	4	1
physical description (e.g. white tower)	1	4	1
magnetic variation	0	4	2
geodetic datum	0	4	2
prohibited and restricted areas	3	3	0
indication of cautionary notes	3	3	0
indication of units of depths and heights	3	3	0
radio characteristics (RACON)	2	3	1
coastal topography	1	3	2
land feature/characteristics	1	3	2
visual and radar conspicuous features	2	2	2

Three methods were used to collect data for an analysis of ECDIS-based navigation functions. These included:

1.) an experimenter's tally of the functions used by the mariner during each scenario
2.) post-scenario confirmation by the mariner of the functions used and additional functions required
3.) a post-experiment questionnaire in which the mariner gave his opinion on whether to display various ECDIS-generated information "always," "at the users option," or "never"

Table 6-3. Mariners' Selection of Most and Least Important Charted Features

Chart Features **MOST** Important	# of mariners		Chart Features **LEAST** Important	# of mariners
indication of floating aids to navigation	5		geodetic datum	4
indication of fixed aids to navigation	4		bottom characteristics	3
navigation lanes/fairways	4		coastal topography	2
coastline/landmass	2		magnetic variation	2
spot soundings	2		anchorages	1
coastal topography	1		details of cautionary notes	1
bottom contours	1		ENC edition date	1
			physical classification (can/nun)	1
			physical description (e.g. white tower)	1
			pilot areas	1

6.4.1 Experimenter's Tally of ECDIS-Based Navigation Functions Used

Most of the navigational data mentioned above were continuously visible on the text display of each ECDIS, making it impossible for an experimenter to determine whether or not the data were being used. Discussion of navigational data used, therefore, is presented below in the summary of the post-scenario questionnaires. The other navigational functions were generally accessed through a series of sub-menus on each ECDIS. Table 6-4 presents the frequency with which each of the navigational functions was accessed, as observed via the remote video camera system.

With the OSL ECDIS, relatively few options were available to the mariner in terms of navigational functions. For the most part, the mariner tended to simply monitor the display, without making a lot of adjustments. Mariners did use the cursor quite often to get ranges and bearings, but since there was not a visibly identifiable mode for this function, occurrences were not recorded by the experimenter.

The mariners tended to simply monitor the Robertson ECDIS as well, though more functions could be and were accessed as can be seen in Table 6-4.

6.4.2 Post-Scenario Questionnaire on ECDIS-Based Navigation Functions Used

The experimenter's tally was supplemented by asking the mariner to check off from a list in the post-scenario questionnaire, the types of navigational data actually used during each

Table 6-4. Observed Use of ECDIS-Based Navigation Functions

OSL Navigational Functions	frequency		Robertson Navigational Functions	frequency
			Enable ARPA targets	6
			target vectors on/off	3
drop radar targets	9		target vectors true/relative	16
adjust radar gain	10		Enable ANTS	37
DR Reset (using cursor)	114		ETA	99
			set position error tolerance	1
			set course to steer error tolerance	1
			set cross-track error tolerance	4
			nav lines	87
			get ARPA target information	35
			range/bearing	170
			manually center chart	52
			own ship's vector on/off	10
			own ship's vector (in minutes)	24
			Track history on/off	17
			track history time labels on/off	12
			DR reset (using cursor)	64
			numerically input own ship's drift	6
			numerically input own ship's set	6
			numerically input own ship's DR position	3

scenario. For the three OSL ECDIS scenarios, the mariners indicated that they all used both the range/bearing to the cursor function and the course-to-steer data. They used the radar overlay and target information in both of the scenarios in which it was available, and the gyro and cross-track distance data in 50 to 75 percent of the scenarios. The mariners also indicated that they never used the latitude/longitude of the cursor's location or of the vessel's location.

Across the four Robertson ECDIS scenarios, the mariners indicated that they all used the information on course, speed, ETA to next waypoint, ship's vector, and distance-to-go, as well as the range/bearing to the cursor function. In the scenario with integrated ARPA targets available, data on selected targets was used by all of the mariners. The track time/history was used in about half of the scenarios, as were the course and speed made good data.

Apparently, the course- and speed-made-good information as well as set and drift data worked only intermittently during the experiment, as the mariners often indicated that they would have used these data if available.

The most commonly mentioned additional data and navigational functions the mariners wanted include ETA to next waypoint, ARPA target vectors (mentioned after OSL scenarios), course- and speed-made-good, course change and chart change alarms, set/drift with mechanism to adjust during DR mode, and CPA/TCPA to the cursor. A complete list of the items mentioned can be found in Table E-3 in Appendix E.

6.4.3 Post-Experiment Questionnaire on ECDIS-Based Navigation Functions

As was the case for the data on electronic chart features presented above, the mariners were asked to give their expert opinion on *when* the ECDIS should display each type of ECDIS-generated information listed in Table 6-5. Table 6-5 below shows the number of mariners (out of six) who indicated whether each item: should be generated and displayed *always*, should be turned on or off with a single keystroke at the *users option*, or should *never* be displayed. The table has been re-organized here to highlight the areas of consensus among the mariners who participated in the study.

The mariners were also asked to choose the three *most* important and three *least* important types of ECDIS-generated information, from the list given in Table 6-5. Table 6-6 presents those features chosen by the mariners.

Table 6-5. Mariners' Recommendations of ECDIS-Based Navigation Functions

ECDIS-Generated Information	Display Always	At Users Option	Display Never
	(# of mariners)		
navigation fault alarm (e.g. GPS down)	6	0	0
own ship outline	5	1	0
display planned trackline	5	1	0
display waypoint and waypoint number	4	2	0
Past track	1	5	0
vector of course and speed made good	1	5	0
display overlay of actual radar	1	5	0
Set and Drift	1	5	0
display range rings	0	5	1
vector of own ship heading and speed	2	4	0
display selected ARPA targets	2	4	0
display current vectors	1	4	1
ETA to waypoint	1	4	1
display dead reckoned position and time	1	4	0
scale bar	1	4	0
chart scale boundaries	1	4	0
display wheel over points/turn radius	3	3	0
grounding alarm	3	2	1
display own ship's safety depth contour	3	1	1
zoom in/ out function	3	1	1
display chart north up and course up	2	3	0
off track alarm	2	3	1
display fix marker and time	1	3	0
course to steer (trackline)	1	3	2
provide method for manual fix taking	1	3	2
display visual limits of lights	1	2	3

Table 6-6. Mariners' Selection of Most and Least Important ECDIS Generated Information

MOST Important ECDIS-Generated Information	# of mariners	**LEAST** Important ECDIS-Generated Information	# of mariners
display planned trackline	4	display visual limits of lights	3
nav fault alarm (e.g. GPS down)	3	course to steer (trackline)	2
display selected ARPA targets	2	display range rings	2
vector of own ship heading / speed	2	zoom in/ out function	1
course to steer (trackline)	1	provide for manual fix taking	1
own ship outline	1	display current vectors	1
display wheel over points/turn radius	1	own ship's safety depth contour	1
Past track	1	display wheel over points/turn radius	1
vector of course and speed made good	1	off track alarm	1
		Past track	1
		vector of own ship heading and speed	1

7.0 RESULTS AND DISCUSSION: ROLE OF ECDIS-BASED RADAR FEATURES IN ROUTE MONITORING

7.1 RADAR, ECDIS, AND ECDIS-BASED RADAR FEATURES IN REDUCED VISIBILITY

7.1.1 The Characteristics of the ECDIS-Based Radar Features

One of the objectives of the experiment was to examine the contribution that the integration of radar features on an ECDIS device might make during route monitoring. Radar features were among the considerations in selecting the experimental ECDIS devices. To review, the Offshore Systems Limited (OSL) device integrated a complete radar video with the relatively simple chart image in its graphic window and presented partial target information (range and bearing of up to four targets) in the alphanumeric window. The Robertson Disc Navigation device was integrated with the ARPA unit and received data from the ARPA about acquired targets. These targets were displayed on the Robertson's more chart-like screen, while the range, bearing, CPA, and TCPA of a selected target was displayed on a separate alphanumeric screen. In addition, the Robertson device allowed the user to add true or relative heading vectors to the targets. These devices are described more completely in Section 2.2 and in Appendix B.

7.1.2 Mariner Preference for ECDIS with Radar Features for Navigation

Each radar was run for one scenario (Scenarios 1 and 4) in reduced visibility (one nautical mile) to allow the participating mariners to examine and experience these different presentations. The mariners' reports of the primary method of navigation used in each segment of those transits is summarized in Table 7-1. These data are a further breakdown of the data presented in Table 5-1. Reports on the Robertson device run in reduced visibility without such features (Scenario 7) are also included to provide a baseline of preference for ECDIS without radar integration. There does appear to be a greater preference for ECDIS with radar integration, especially in the coastal phase of navigation. The major competitor for the use of ECDIS for navigation in the coastal phase of the transit is the radar/ARPA on the bridge. In the harbor, both the radar/ARPA

Table 7-1. Primary Method of Navigation in Reduced Visibility as Reported by Mariners

BRIDGE CONDITIONS	PLOTTING/ PAPER CHART	RADAR/ ARPA	VISUAL PILOTING	ECDIS	TOTAL NUMBER SEGMENTS
	PROPORTION OF SEGMENTS USING METHOD IN EACH BRIDGE CONDITION				
COASTAL PHASE OF NAVIGATION					
OSL with radar overlay (Scenario 1)	0.00	0.00	0.00	**1.00**	2
Robertson with ARPA targets (Scenario 4)	0.00	0.00	0.00	**1.00**	5
Robertson no ARPA targets (Scenario 7)	0.00	0.75	0.00	**0.25**	4
HARBOR/HARBOR APPROACH PHASE OF NAVIGATION					
OSL with radar overlay (Scenario 1)	0.00	0.00	0.12	**0.88**	8
Robertson with ARPA targets (Scenario 4)	0.00	0.20	0.00	**0.80**	5
Robertson no ARPA targets (Scenario 7)	0.00	0.24	0.08	**0.68**	25

and visual piloting are mentioned. The paper chart is not mentioned. Unfortunately, the total number of segments is very small which reduces the reliability of these observations. Counts are small for the OSL because only two mariners ran that

condition; counts are small for the Robertson because that scenario was a short transit with fewer segments.

7.1.3 Effects on Workload and Safety

Analysis of the quantitative performance data collected showed no differences in navigation workload, collision avoidance workload, or accuracy of ship tracks that could be attributed to the presence or absence of radar features on the ECDIS. Even if the mariners did have a preference for the presence of the features, any contributions were too subtle to affect the measures associated with navigation. There seems to be no obvious reason why radar features should affect navigation workload or cross-track distance beyond the effects that were observed with the basic ECDIS (as described in Sections 5.2 and 5.3).

Because the experimental transits were designed with considerable traffic, the mariners had a major need for ARPA for collision avoidance. It became clear during the scenarios that, whether or not radar features were available on the ECDIS, each mariner made continuous use of the ARPA unit and its capabilities. Indeed, the mariners indicated that this was precisely because they required more ARPA-type capabilities than were available on either system. They did not consider the partial ARPA presentations adequate for their need and continued to use both the ECDIS and the radar/ARPA, with the result that there was no reduction in the collision avoidance workload. The available performance data are summarized in Appendix E.

7.2. MARINERS" REACTIONS TO RADAR FEATURES

The mariners' opinions on the potential contribution of integrated radar features with ECDIS were expressed during both the post-scenario debriefings and in the post-experiment questionnaire. (Samples of these questionnaires appear in Appendix D.) All the mariners felt that radar features should be integrated with ECDIS, but there were some differences of opinion on the nature of that integration. Two of the mariners indicated that a user-selectable level of radar information is preferable: from none, to only ARPA targets, to the complete radar overlay. One mariner preferred ARPA targets only, while another preferred the radar overlay. Another mariner indicated that ECDIS features and functions should be integrated with the ARPA rather than the reverse. His argument was that the primary concern for mariners is collision avoidance, that many ECDIS functions

can already be performed on the ARPA, and that the ECDIS would be used only as a monitor anyway, with "the mariner keeping his head mainly in the radar."

Both advantages and disadvantages of having an integrated radar as part of the ECDIS were mentioned. The most basic advantage mentioned was that the mariner would need to monitor only one screen to obtain all the information he needed, and would not have to switch back and forth between two systems (although with the presentations that they saw, the mariners did switch back and forth). In addition, the visual confirmation of electronic chart data in relation to the radar return of these charted features would provide confidence in the accuracy and quality of the ECDIS data. Overall, the mariners indicated that integrated chart and radar would have a positive influence on navigational safety, both by increasing the situational awareness of the conning officer and by facilitating the identification of radar targets as either vessels or charted objects. The "bird's eye view" of the waterway with heading vectors on the traffic would provide the mariner with a clearer overall picture of the situation. One mariner mentioned that the strain and fatigue associated with arrivals and departures in reduced visibility would be reduced, and another conjectured that local authorities might eventually allow ships so-equipped to proceed into and out of port under zero visibility conditions. (There were only minor effects on "situational awareness," as it was measured in this experiment. See Section 4.0 and Appendix D.)

A number of limitations were also discussed. The mariners generally agreed that the potential for sea/rain clutter to obliterate chart features is a problem that must be considered. Each mentioned that the presentation of the radar return that they saw was poor and must be improved, at least to the current level of technology. Moreover, additional ARPA data and capabilities were considered essential in order for any degree of radar integration to be useful. The mariners were emphatic about needing "an excellent, fully capable radar/ARPA at all times." During the Robertson scenarios in which targets acquired on the ARPA were automatically transferred to the ECDIS, it was noted that there were potential dangers with this arrangement. Even in an "auto-acquire" mode, the ARPA does not always acquire every target and often acquires inappropriate ones. Moreover, the ARPA can lose targets on occasion. They indicated that a mariner could get into serious trouble if he got absorbed in watching the ECDIS display, thinking that he had information on all of the existing traffic and ignoring the radar. One mariner also indicated concern that radar integration might cause a mariner, concentrating on the act of collision avoidance, to be distracted from the act of navigation.

The basic objectives of a radar overlay integrated with ECDIS need to be considered carefully in order to maximize its contribution to the integrated system. Three potential objectives are: to check on the accuracy of position information, to position own ship during a manual position update procedure, and to replace radar/ARPA during collision avoidance. Each of these objectives requires a different level of radar information to be integrated. The mariners rated both the usefulness and safety of using radar (or target) overlay to accomplish each of these objectives. These ratings were done after experiencing each of the scenarios in which radar information was integrated with the ECDIS (Scenarios 1, 3, and 4). Ratings varied on a "1" to "5" scale between "not useful"/"unsafe" to "very useful"/"very safe". Table 7-2 shows the mean ratings the mariners gave for each of these three objectives. The data from individual scenarios are also given since the number of responses is quite variable and the means quite different between scenarios. (In Scenario 3 they used the radar overlay as a mechanism to manually update own ship's position.) (The rating scale as they saw it appears in the post-scenario questionnaire presented in Appendix D.)

Overall, the mariners felt that using the radar overlay for <u>checking the accuracy of their position</u> is both a useful and a safe procedure. In each of the scenarios, the mean ratings were 4.0 and 4.33 or better, for usefulness and safety, respectively.

For <u>collision avoidance</u> purposes, however, opinion varied to both ends of the scale. The OSL full radar overlay (Scenario 1) was considered not useful and very unsafe as it was presented during the experiment (mean ratings were 1.17 and 1.00, respectively). The Robertson target overlay (Scenario 4) was generally considered to be very useful for collision avoidance (mean rating was 4.5), but averaged only 3.5 for safety.

As the primary method for manually updating the <u>vessel's position</u> on the display, scores on both usefulness and safety ranged from 1 to 5 across the scenarios. Ratings given after Scenario 3, in which manual updating was required, averaged 4.5 and 3.5 for usefulness and safety, respectively, although unfortunately these numbers include responses from only two mariners.

Table 7-2. Mariners' Ratings on the Usefulness and Safety of Radar Features for Several Possible Objectives

Radar Overlay Function:	Check on Accuracy of Position		Primary Method of Manual Positioning		Collision Avoidance	
	Usefulness	Safety	Usefulness	Safety	Usefulness	Safety
Scenarios 1, 3, and 4 Combined						
mean	4.18 (n = 11)	4.64 (n = 11)	3.7 (n = 10)	3.2 (n = 10)	3.32 (n = 11)	2.9 (n = 10)
standard deviation	0.87	0.5	1.42	1.4	1.85	1.73
Scenario 1 (OSL with Auto Update and Full Radar Overlay)						
mean	4.0 (n = 3)	5.0 (n = 3)	2.5 (n = 2)	2.5 (n = 2)	1.17 (n = 3)	1.0 (n = 2)
standard deviation	1.0	0.0	0.71	0.71	0.29	0.0
Scenario 3 (OSL with Manual Update using Full Radar Overlay)						
mean	4.0 (n = 2)	5.0 (n = 2)	4.5 (n = 2)	3.5 (n = 2)	3.0 (n = 2)	3.0 (n = 2)
standard deviation	1.41	0.0	0.71	2.12	2.83	2.83
Scenario 4 (Robertson with Auto Update and Target Overlay)						
mean	4.33 (n = 6)	4.33 (n = 6)	3.83 (n = 6)	3.33 (n = 6)	4.5 (n = 6)	3.5 (n = 6)
standard deviation	0.82	0.52	1.6	1.51	0.84	1.38

These data and the comments made by the mariners suggest, first, that a radar overlay without additional ARPA features is really only useful (and safe) for confirming own ship's position and does not aid collision avoidance and, second, that the target overlay is considered more useful and safe for collision avoidance, probably because CPA and TCPA were also available on each target.

8.0 CONCLUSIONS

8.1 ECDIS IN ROUTE MONITORING

8.1.1 ECDIS and the IMO Performance Standards

This study was designed to examine a number of broad issues from the IMO Performance Standards for ECDIS (International Maritime Organization, 1989,1994). The following is a brief overview of the conclusions on each issue:

- ECDIS has the potential to improve the safety of navigation, primarily by improving the precision of navigation.
- ECDIS has the potential to reduce the workload for navigation, primarily by freeing the mariner from the time-consuming task of plotting on the paper chart.
- All the chart features that the mariners used or wanted for the dynamic process of route monitoring are required by the IMO.
- The radar integration on the experimental systems did not provide the freedom from clutter the mariners wanted on an integrated display nor the complete ARPA information they wanted for a primary radar.

Each of these issues is discussed further below. A listing of all the items in the IMO Performance Standards for ECDIS (International Maritime Organization, 1993) can be found in Appendix F. Relevant comments based on the findings of this study are matched to those items.

8.1.2 ECDIS and Bridge Operations

The IMO/IHO Harmonization Group on ECDIS, in their draft resolution (International Maritime Organization, 1992), stated that "as ECDIS comes into general use as part of an overall bridge system, functions that extend beyond chart equivalence will become more clearly defined." To quote one of the participating mariners, "The ECDIS units used in the experiment perform roughly the same mechanical function as the human navigator working on a paper chart; they take position data from an outside source and indicate that position on a graphical display of a portion of the earth's surface. The units are more than replacements for the chart -- they are replacements for human activity." The experiment

reported here is an exploration of how ECDIS might affect the "overall bridge system" and "human activity."

8.2 ECDIS AND SAFETY OF NAVIGATION

The study showed that ECDIS's potential to match and improve upon the safety of navigation, compared to conventional procedures. Because there is no universally accepted measure of "safety," a variety of measures were examined. With ECDIS, mariners were able to achieve a greater accuracy of navigation as measured by a smaller cross-track distance of the ship from the planned track line. With ECDIS, there was evidence that mariners had improved geographic "situational awareness" and that they made fewer navigation "errors" as rated by an experimenter. With ECDIS, mariners reported: a lower navigation workload, a smaller proportion of time spent on navigation, and, as a result, a higher proportion of time spent on the higher risk collision avoidance task.

Note that a number of studies have demonstrated that navigational displays presenting cross-track distance can support highly accurate trackkeeping. Such findings have been reported by a number of simulator studies (Smith and Mandler, 1992) and verified at sea (Gonin and Crowell, 1992). These findings, that ECDIS both supports more accurate ship control and allows more time to be spent on non-navigation tasks, also agree with simulator evaluations of automated "one man bridge" operation (Schuffel, Boer, and van Breda, 1989).

8.3 ECDIS AND WORKLOAD OF NAVIGATION

The strongest and most consistent finding was that the availability of ECDIS on the bridge substantially reduced the mariner's workload for navigation. This reduction was demonstrated by the time distribution reports, by the National Aeronautical and Space Administration's Task Load Index (NASA-TLX) (Hart and Staveland, 1988), and in the mariners' spontaneous comments. The savings in workload were demonstrated with automatic updating of own ship's position and without a requirement to maintain an additional plot on a paper chart.

8.4 ECDIS SYSTEMS, CHART FEATURES, AND NAVIGATION FUNCTIONS

8.4.1 System Requirements in Route Monitoring

The following requirements were identified for the effective use of ECDIS for route monitoring in the Coastal and Harbor/Harbor Approach phase of navigation (Federal Radionavigation Plan, 1992): accuracy of all charted information, accuracy and automatic updating of own ship's position information, the accurate scaling of own ship's outline in narrow channels, the constant availability of a selected subset of information, the rapid availability of a larger subset of information for reference, and the provision of operator-friendly navigational functions.

The differences between the two commercial devices used in the experiment -- differences in user interface, in chart presentation, and in radar features -- seemed quite substantial during the planning of the experiment. While individual mariners had strong preferences for specific features provided by one or the other of the devices, there were no major or consistent differences between the two devices on any of the performance measures examined. It seems appropriate to conclude that the study successfully investigated ECDIS principles more general than reactions to the specific devices.

8.4.2 Charted Features Needed in Route Monitoring

The findings suggest a distinction between two functions of a navigational chart: a dynamic function for route monitoring, which needs only the information used in ship control, and a static function as a geographic information system (GIS), which provides much more extensive information for reference.

For the "dynamic" process of route monitoring, the mariners used, or recommended, only a very simple subset of charted features, features that outline the safe water available for the transit. The charted features recommended by a majority of mariners for continuous display were:

- coastline/landmass
- fixed and floating aids to navigation
- federal channel lines
- navigation lanes and fairways
- isolated dangers

These features are all in the "display base" or "standard display" in the IMO Performance Standards (International Maritime Organization, 1994). The recommendation of only a simple display for route monitoring is consistent with conclusions in a number of other papers (Smith, 1993; Smith and Mandler, 1992; Bianchetti, 1992; and Roeber, 1992).

A much larger subset of charted features was recommended to be user-selectable or was referenced briefly on the paper chart on the bridge. Examples of the most frequent of these are:

- soundings, depths, bottom contours, etc.
- aids to navigation characteristics, names of points, etc.

8.4.3 ECDIS-Based Navigation Functions Needed in Route Monitoring

Navigational data and functions recommended for continuous display by a majority of the mariners included:

- planned trackline
- navigation fault alarm (e.g., GPS down)
- selected ARPA target
- own ship outline
- vector of own ship course and speed

Additional functions were used during the scenarios, or recommended by a minority of the participating mariners.

Given the capabilities of a computer, the functions that might be added to an ECDIS are limited only by the ingenuity of the manufacturers. There should be concern not only that the functions wanted be available to the mariner, but also that a system not be overly complicated, cluttered, and confused. As with chart features, there should be a "base set" of navigation functions to be provided in every mode on every model by every manufacturer. In addition, there should be additional functions to be selectable by the user. Manufacturers could have the opportunity for product differentiation and innovations as long as they do not interfere with the base set. Ideally, there should be sufficient standardization across systems that an experienced mariner can make immediate, effective use of a different system.

8.5 ECDIS, RADAR OVERLAY, AND INTEGRATED NAVIGATION SYSTEMS

8.5.1 Roles of Radar and ECDIS

The results of the experiment were equivocal with respect to the contribution of radar integration. The mariners did report using ECDIS with radar features more frequently for navigation than ECDIS without these features. However, the analysis found no significant differences on any quantitative performance measure. There seems to be no obvious reason why radar features should affect navigation workload or cross-track distance beyond the effects that the basic ECDIS were observed to have. Perhaps other performance measures applied under other conditions would have found objective evidence of an advantage.

Mariners made considerable use of the separate radar/ARPA on the bridge for collision avoidance, finding the incomplete ARPA capabilities on the two ECDIS devices inadequate for their needs. Presumably for this reason, the radar features did not have a measurable effect on collision avoidance workload, either.

When questioned, all the mariners felt that radar overlay, or an integration of radar and ECDIS, could be a valuable asset on the bridge. Possible positive contributions mentioned included: savings in workload when using only one display, confirmation of the accuracy of ECDIS information, and increased situational awareness. The lack of these positive effects in the experiment was attributed to a "cluttered" display and to incomplete ARPA information that forced them to continue to use the separate ARPA.

8.5.2 A Fully Integrated Navigation System

Given that the watchstanders consider the radar/ARPA to be critical for collision avoidance during route monitoring, the designers of ECDIS must consider how these two systems will be used together. The mariners' comments suggest that a full integration would provide increased safety and confidence and reduced workload. A major concern is the very cluttered and complex display that could potentially result. Engineering improvements, such as high resolution screens or minimal sea return and clutter, would allow the clearer presentation of more information on a single screen. But, the final design of such integrated systems is a human factors problem. A fully capable integration of

radar/ARPA and ECDIS should be done with careful design and planning and with the inclusion of the user in the process.

The relatively small subset of chart information actually needed during route monitoring suggests that the complexity contributed by the chart could be reduced. Five of the six mariners suggested a simplification of the chart on ECDIS to make room for a radar overlay. Removing soundings or water depth was frequently suggested as a way to remove clutter. A contour representing "good water" for the draft of own ship was suggested instead. (This last feature is in the IMO PS, Appendix 2.) Several mariners suggested that the extent of the radar overlay, complete video or ARPA targets only, should be user-selectable. The sixth felt that a simplified chart should be an overlay on the radar/ARPA, which he considered the "basic" display. All agreed that all chart information should be easily available during monitoring, by simple operator actions. (This last feature is implied by the IMO PS, Item 6.1.) All chart information must be available for passage planning, but not necessarily on the same display used for route monitoring.

8.6 RESEARCH METHODOLOGY

8.6.1 Designing Watchstanding Scenarios

The technique of dividing watchstanding into Navigation, Collision Avoidance, and Bridge Management tasks resulted in scenarios with good "face validity," had good mariner acceptance, and was generally effective as a research tool. Because the opportunity and resources were not available for extensive, preliminary testing, there were unintended differences in collision avoidance or navigation workload among the scenarios. With revision, the existing scenarios provide a valuable resource for future use.

8.6.2 Measuring Situational Awareness

The detailed geographic information presented by ECDIS suggested a hypothesis of increased "geographic" situational awareness (Sarter and Woods, 1991) with its use. The procedures developed for measuring such an effect showed a small amount of sensitivity to experimental manipulations. Unfortunately, the sensitivity was not sufficient to allow any reliable conclusion. However, the results do suggest that, with further development, the measurement of situational awareness might become a valuable tool in the analysis of watchstanding performance and/or navigation displays.

8.6.3 Measuring Mariner Workload

The National Aeronautic and Space Administration's NASA Task Load Index (NASA-TLX) had good mariner acceptance because of its face validity. The opportunity to report the high workload made the (intentional) artificiality of the one-officer bridge more acceptable and more meaningful to the mariners. For this marine operator/system evaluation, it proved to be an effective research tool that was sensitive to the experimental manipulations, i.e., differences among scenarios and ECDIS modes.

8.6.4 A Closer Look at the Radar Overlay

The present experiment provided the mariners with the opportunity to experience and react to two different integrations of ECDIS and radar features. However, the experiment was not effective in measuring any possible subtle effects that the partial integration of radar might have on navigation performance. An experiment that would be more likely to reveal these effects would require the following: greater similarity or constancy of collision avoidance or bridge management conditions across scenarios, preliminary testing of the scenarios for equivalency of any remaining differences, no separate ARPA that would allow the mariners to minimize their dependence on the test system, and a more extensive data analysis examining CPA and distance or time of first response to the traffic encounter.

8.6.5 Validation of the Findings at Sea

Several of the performance measures used, and the conclusions based on them, could and should be validated by sea trials using ECDIS. The most important of these is the mariner's report of the distribution of attention among possible methods of navigation: paper chart, radar, visual piloting, and ECDIS. The paper chart and ECDIS are the same on the simulator or at sea, but the radar and, most especially, the visual scene are simplified on the simulator. Validation studies done for earlier versions of CAORF's visual scene found that mariners made more use of the radar and less use of the visual scene on the simulator, compared to at-sea performance (Hammell, 1979).

The simulator experience with measures of workload and accuracy of ship tracks using ECDIS suggests that these would be valuable tools for sea trials. At the same time, their use in sea trials would provide validation for the simulator findings. Note that increased

accuracy of ship tracks, using the OSL Precision Integrated Navigation System (PINS) 9000, has been demonstrated at sea (Gonin and Crowell, 1992).

Mariners' preferences for charted features and navigation functions could also be validated at sea. It is probably not important exactly how preference is measured. On a real ship, questionnaires may be more practical than video monitors. It may be that preferences might change with exposure to the devices over the longer time periods possible on a real ship.

8.7 FURTHER ECDIS RELATED ISSUES

8.7.1 Evaluation of the Operator Interface

Many interface and display issues were not addressed in the present study. These fall into two broad categories. The first category includes such navigation display issues as: screen resolution needed to present navigation data, the speed of re-draw needed for accurate ship control, appropriate colors and symbols to carry information, etc. Such specialized features as error ellipses and steering displays might be included in this first category, as well. The second category of issues is generic to any operator/computer interface: color palette for viewing conditions, controls, data input devices, etc. These two categories of issues were beyond the scope of the present study. This was true both because the commercial devices were limited in the number of variations in display and interface that could be examined, and because simulator time and resources were better spent examining the more dynamic issues of route monitoring. Such issues are more efficiently examined by the application of existing standards for interfaces, in the laboratory, or at sea.

8.7.2 ECDIS for Route Planning

The use of ECDIS for route planning was examined only peripherally in this study. Experimenters prepared the planned track on the ECDIS systems both to control the tracks taken during the scenarios and to allow the test mariners to spend more time on the simulator. The use of ECDIS for route planning is an issue that could be better examined in a setting where mariners would have the use of the system over longer periods of time. Their experience would identify the charted features and navigation functions needed.

8.7.3. Effects of ECDIS on Collision Avoidance and Bridge Management

The effects of ECDIS on the safety of collision avoidance have not been fully examined. There is evidence from earlier simulator experiments that mariners using navigational displays with the resulting greater knowledge of their position tend to make greater excursions from the planned track to avoid traffic encounters (Schryver, 1983; Aranow, 1979; Hayes, 1979; CAORF Research Staff, 1978b). A simulator study has also found larger distances from obstructions (e.g., bridge pilings) (O'Hara and Brown, 1985).

This study found no effects of ECDIS on the bridge management workload. A system based on a microprocessor could provide such management capabilities as recording track histories, logging communications, keeping notes accumulated during passage planning or earlier passages, etc.

8.7.4 Training for ECDIS Use

The issue of training for ECDIS use was dealt with only very peripherally in this study. The test mariners were given brief training and testing on the use of each of the systems before the experimental transits. Their responses on the questionnaire indicated that this training was sufficient for the purposes of the experiment and that they did not think that special training and certification would be needed for ECDIS use. However, their need for an understanding of the system was limited because they did not do passage planning or concern themselves with maintenance, chart updating, etc. The issue of training for this new technology is a complex one which is being dealt with elsewhere (Flinn and Stewart, 1993; Sanquist, Lee, Mandler, and Rothblum, 1993; Sanquist, Lee, McCallum, and Smith, 1995; and Sanquist, Lee, and Rothblum, 1994).

8.7.5 ECDIS as Automation

Many ECDIS issues are general to the use of automated systems: effects on safety, on situational awareness, on workload, on a need for special training, etc. The consequences of the increased use of technology on ships and related changes in the mariner's role are of great interest in the marine industry at the present time. Many of the comments from the mariners who participated in this study suggest concern that the consequences might be negative as well as positive: "junior officers" will be over-confident or overly complacent, they will fail to "keep proper look out" or fail to notice targets not acquired by ARPA, they

will not acquire or will not maintain the necessary skills to function in case of system failure, they will not be aware of system inaccuracies or malfunction, "owners" will take a man off the bridge for every ECDIS they put on it, etc.

Because of the broad implications of these types of issues for maritime safety, the USCG is involved in a major study of the effects of automation (Sanquist, Lee, Mandler, and Rothblum, 1993; Sanquist, Lee, McCallum, and Smith, 1995; and Sanquist, Lee, and Rothblum, 1994). The study will develop research tools to determine the effects of automated systems on mariner tasks and on the knowledge, skills, and abilities needed to perform those tasks. The potential use of simulators in testing mariner qualifications and in training for the use of automated systems will be examined. The study findings will support the USCG in regulating qualifications for merchant mariners and in setting training requirements.

REFERENCES

Abacus Concepts, SuperANOVA. Abacas Concepts, Inc., Berkeley, CA, 1989.

Aretz, A.J. The Design of Electronic Map Displays. Human Factors. 33(1), 85-101. February 1991.

Alexander, L. and M.J. Casey. Cooperative ECDIS Projects Between United States and Canada. In Proceedings of the First Annual Conference and Exposition for Electronic Chart Display and Information Systems, Baltimore, MD. Pp. 128-136. February 28-29, 1992.

Aranow, P.I. Summary Assessments of CAORF Collision Avoidance Studies. In Proceedings of the Third CAORF Symposium, National Maritime Research Center, Kings Point, N Y, 1979.

Bianchetti, F. The ECDIS Paradox, A Controversial View on Navigation, Freedom and Safety at Sea. In Proceedings of the First Annual Conference and Exposition for Electronic Chart Display and Information Systems, Baltimore, MD. Pp. 113-122. February 28-29, 1992.

CAORF Research Staff. MRIT Navigation Aid Experiment. CAORF Technical Report 34-7801-01, National Maritime Research Center, Kings Point, NY, 1978a.

CAORF Research Staff. Collision Avoidance Performance with Visual Sighting, Radar, and Collision Avoidance Systems. CAORF Technical Report 13-7701-01, National Maritime Research Center, Kings Point, NY, 1978b.

CAORF Staff. Kill Van Kull/Newark Bay Channel Improvements Simulation Study: Acceptance Area J. CAORF Technical Report Number 27-9033-02, National Maritime Research Center, Kings Point, NY, 1992.

Centre for Marine Simulation (CMS). Passage Execution: A Comparison of Human Performance Using Electronic and Paper Charts. Prepared for the Canadian Hydrographic Service, Dartmouth, Nova Scotia. Research Report - 940915, 1994.

Cooper, R.B. and W.R. Bertsche. An At-Sea Experiment for the Comparative Evaluation of Radar Piloting Techniques. United States Coast Guard, Washington DC, November 1981.

Cooper, R.B., and K.L. Marino. Simulator Evaluation of Electronic Radio Aids to Navigation Displays -- the Mini-experiment. CG-D-59-80, United States Coast Guard, Washington DC, September 1980.

Cooper, R.B., K.L. Marino, and W.R. Bertsche. Simulator Evaluation of Electronic Radio Aids to Navigation Displays, the RA-1 Experiment. CG-D-49-81, United States Coast Guard, Washington DC, January 1981a. (NTIS AD-A106941)

Cooper, R.B., K.L. Marino, and W.R. Bertsche. Simulator Evaluation of Electronic Radio Aids to Navigation Displays, the RA-2 Experiment. CG-D-50-81, United States Coast Guard, Washington DC, April 1981b. (NTIS AD-A106672)

Crenshaw, R.S., Jr. Naval Shiphandling 4th ed. Naval Institute Press, Annapolis, MD, 1975.

Federal Radionavigation Plan. Performing Organization Report Number DOD-4650.5/DOT-VNTSC-RSPA-92-2. United States Department of Transportation (DRT-1) and United States Department of Defense (ASD/C^3 I), Washington, DC, 1992.

Flinn, D.C., and R.S. Stewart. The Educational Process Developed at the United States Merchant Marine Academy for the Training of Cadets in the Application of Electronic Display Information Systems in Vessel Operations. In the Proceedings of The Second Annual Conference and Exposition for Electronic Chart Display and Information Systems, ECDIS '93. Baltimore Maryland, March 8 &9, 1993.

Fritzke, H.E. and CAORF Staff. The Master Mariner Readiness Course: A Program to Enhance the Support of National Defense. In Proceedings of the Sixth CAORF Symposium, National Maritime Research Center, Kings Point, NY, May 1985.

Gonin, I.M. and R.D. Crowell. U.S. Coast Guard Electronic Chart Display and Information System (ECDIS) Field Trials: Preliminary Results. In Proceedings of the First Annual Conference and Exposition for Electronic Chart Display and Information Systems, Baltimore, MD. February 28-29, 1992.

Gonin, I.M. and M.K. Dowd. 1993 At Sea Evaluation of ECDIS. Proceedings of 1994 National Technical Meeting of the Institute of Navigation, 24-26 Jan 1994, San Diego, CA.

Gynther, J.W. Measuring the Effectiveness of Shiphandling Simulator Based Training. In Proceedings of the Society for Computer Simulation. Pp. 53-58. 1985.

Gynther, J.W. and M.W. Smith. Radio Aids to Navigation Requirements: The 1988 Simulator Experiment. CG-D-08-90, United States Coast Guard, Washington DC, November 1989. (NTIS AD-A226235)

Hammell, T.J. Validation of Mates Behavior at CAORF. CAORF Technical Report 90-7802-01, National Maritime Research Center, Kings Point, NY, 1979.

Hart, S.G. and L.E. Staveland. Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research. In Hancock & Meshkati (Eds.), Human Mental Workload, North Holland Press, Amsterdam, 1988. (Elsevier Science Publishing Company, Inc. New York).

Hayes, J. Value of an Anti-Grounding Collision Avoidance Display in Restricted Waterways. In Proceedings of the Third CAORF Symposium, National Maritime Research Center, Kings Point, NY, 1979.

Hayes, J. and E.D. Wald. Effectiveness of Three Electronic Systems for Collision Avoidance and Grounding Avoidance: a Simulator Investigation in a Congested Harbor. CAORF Technical Report 13-7811-01, National Maritime Research Center, Kings Point, NY, 1980.

J.J. Henry Co., Inc. and Systems Control Inc. CAORF Simulator Coefficient Estimation Procedure for a Containership Type Vessel. National Maritime Research Center, Kings Point, NY, 1979.

International Hydrographic Organization. Provisional Specifications for Chart Content and Display of ECDIS, Special Publication No. 52, International Hydrographic Bureau, Monaco, 1990.

International Maritime Organization. Annex 1 List of Matters for Use in Examining Subject Areas Which May Have Human Factor Implications. April 1992.

International Maritime Organization. Memo: IMO Draft Performance Standards for ECDIS: Human Factors Evaluation. August 1992.

International Maritime Organization. Performance Standards for Electronic Chart Display and Information Systems (ECDIS). MSC/circ.637, 27 May 1994.

International Maritime Organization. Draft Performance Standards for Electronic Chart Display and Information Systems (ECDIS). NAV39/31, Annex 6, 29 September, 1993.

International Maritime Organization. Draft Performance Standards for Electronic Chart Display and Information Systems (ECDIS). HGE Version 2.0, September 1992.

International Maritime Organization. Provisional Performance Standards for Electronic Chart Display and Information Systems (ECDIS). NAV 35/WP.31989.

Kaufman, E.J. The Development of Performance Measures for Marine Simulation Through the Analysis of Shiphandling in Enclosed Waters. In Proceedings of the Sixth CAORF Symposium, National Maritime Research Center, Kings Point, NY, May 1985.

Lysaght, R.J., S.G. Hill, A.O. Dick, B.D. Plamandon, P.M. Linton, W.W. Wierwille, A.C. Bittner, and R.J. Wherry. Operator Workload: Comprehensive Review and Evaluation of Operator Workload Methodologies. Technical Report 851. United States Army Research Institute for the Behavioaral and Social Sciences. Alexandria, VA, 1989.

Mandler, M.B., and M.W. Smith. Precision Electronic Navigation in Restricted Waterways. In Proceedings of the Institute of Navigation. Forty-sixth Annual Meeting. Atlantic City, NJ, June 1990.

Mandler, M.B., M.W. Smith, and J.W. Gynther. Precision Electronic Navigation in Restricted Waterways. Navigation . Vol.37, No.4, Winter, 1990-91.

Maxwell, S.E. and H.D. Delaney. Designing Experiments and Analyzing Data: A Model Comparison Perspective. Ch. 11. Wadsworth Inc. Belmont, CA: 1990

MSI/CAORF Staff. Proposal for an ECDIS Research Program. CAORF 26-9031-01A, Computer Aided Operations Research Facility, National Maritime Research Center, Kings Point, NY, July 1991.

Meurn, R.J. The Watchstanding Guide for the Merchant Officer. Cornell Maritime Press, Centreville, MD, 1990.

NASA Task Load Index. V1.0. Paper and Pencil Package. Human Performance Research Group, NASA Ames Research Center, Moffett Field CA, 1988.

O'Hara, J.M. and W.S. Brown. An Investigation of the Relative Safety of Alternative Navigation System Designs for the New Sunshine Skyway Bridge: A CAORF Simulation. CAORF Technical Report Number 26-8232-04. National Maritime Research Center, Kings Point, NY, September 1985.

Radio Technical Commission. RTCM Recommended Standards for Electronic Chart Display and Information Systems, Version 1.0. RTCM Special Committee No. 109., RTCM Paper 132-89/SC 109-72, December 15, 1989.

Radio Technical Commission. RTCM Recommended Standards for Electronic Chart Systems (ECS), Report on ECS Working Group to RTCM Special Committee No. 109, June 20 1994.

Riek, J.R. and S.C. Hargis. Santa Barbara Channel Risk Management Program. CAORF Technical Report Number 24-8015-01, National Maritime Research Center, Kings Point, NY, 1981.

Roeber, J. 1992. Application of Electronic Charts in Integrated Bridge Systems. In Proceedings of the International Hydrographic Organization, Baltimore, MD. February 25-28, 1992.

Roeber, J.F. Black-Box Harbor Navigation (Look what the microprocessor hath wrought). In Proceedings of the Marine Safety Council, September/October 1981.

Sanquist, T.F., J.D. Lee, M.B. Mandler, and A.M. Rothblum. Human Factor Plan for Maritime Safety. CG-D-11-93. U.S. Coast Guard, Washington DC. 1993. (NTIS: AD-A268267)

Sanquist, T.F., J.D. Lee, M.C. McCallum, and M.A. Smith. Qualification and Training for Automated Ships II: Skill Assessment and Field Observations. Battelle Seattle Research Center, Seattle, WA for U.S. Coast Guard Res. and Dev. Center, Groton, CT. In Preparation, 1995.

Sanquist, T.F., J.D. Lee, and A.M. Rothblum. Cognitive Analysis of Navigation Tasks: A Tool for Training Assessment and Equipment Design. CG-D-19-94. U.S. Coast Guard, Washington DC. 1994 (NTIS: AD-A284392)

Sarter, N.B. and D.D. Woods. Situation Awareness: A Critical But Ill-Defined Phenomenon. The International Journal of Aviation Psychology, 1 (1), 45-57. 1991.

Schwartz, D. Training for Situational Awareness. In Proceedings of the Fifth International Symposium on Aviation Psychology. Ohio State University, April 17, 1989.

Schryver, J.C. A Steering Quality Profile for General Application to Channel Navigation. In Proceedings of the Sixth CAORF Symposium, National Maritime Research Center, Kings Point, NY, May 1985.

Schryver, J. Evaluation of ARPA Display Modes and Traffic Assessment through CAORF Simulation of Collision Avoidance Situations. CAORF Technical Report Number 13-8128-02, National Maritime Research Center, Kings Point, NY, 1983.

Schuffel, H., J.P.A. Boer, and L. van Breda. The Ship's Wheelhouse of the Nineties: the Navigation Performance and Mental Workload of the Officer of the Watch. Journal of Navigation, 42 (1), 60-72. 1989.

Smith, M.W. Precision Electronic Navigation in Restricted Waterways: a Simulator Investigation. United States Coast Guard Research and Development Center, Groton CT. In preparation, 1993.

Smith, M.W. and Mandler, M.B. Human Factors Evaluations of Electronic Navigation Systems. In Proceedings of the First Annual Conference and Exposition for Electronic Chart Display and Information Systems, Baltimore, MD. February 28-29, 1992.

Smith. M.W., M.B. Mandler, J. Mazurkiewicz, J.W. Gynther, and W.K. Brown. Investigations of Piloted Performance in Restricted Waterways: Precision Electronic Navigation and Ship Performance. In Proceedings of the Joint International Conference on Marine Simulation and Ship Manoeuvrability, MARSIM & ICSM, Tokyo, Japan, 1990.

Williams, K.E., J. Goldberg, and D.S. Nieri. Passage Planning: an Objective Assessment of a Bridge Management Procedure Versus Integrated Electronic Aids. CAORF Technical Report 36-8003-01, National Maritime Research Center, Kings Point, NY, 1982.

APPENDIX A.0

DESCRIPTION OF MSI/CAORF FACILITY

The Computer Aided Operations Research Facility (CAORF), located on the grounds of the United States Merchant Marine Academy, Kings Point, New York, contains a sophisticated ship maneuvering simulator. CAORF has been operated by MarineSafety International (MSI) since 1978 for controlled research into man/ship/environment problems. Its main focus is to provide a realistic simulation of the bridge environment, ship response, and waterway to investigate how these factors interact with and influence the shiphandler's ability to maneuver vessels under various conditions.

The emphasis on the "man-in-the-loop" affords a well rounded approach, the purpose of which is to examine the human element in marine operations.

Research conducted at CAORF is sponsored by either the U.S. Department of Transportation, Maritime Administration (MarAd) or clients which represent industry or other government agencies. MarAd sponsored projects typically address research questions relevent to a wide section of the maritime industry. After a specific question is identified, preliminary analysis is made by marine research specialists at CAORF to determine whether CAORF on-line or off-line analysis is required. Based on these findings, a research plan and detailed experimental design may be implemented and executed, the results of which are freely publicized.

A similar process is used with other clients. The client and CAORF staff will draw up a specific statement of objectives that defines the research plan. Next, a specific program may be implemented, including the following tasks:

Experimental Design - definition of variables of interest, performance measures, and requirements for data analysis.

Planning and Preparation - development of scenarios, specifications of types of ships, speeds, courses, and initial positions of ships in the scenarios, and collection of pertinent data.

Data Base Construction - generation of visual, radar, situation display, plotting, and depth/current/bank data bases.

Subject Acquisition - acquisition and scheduling of practicing deck officers (masters, mates, pilots) for participation in the scenarios as the "man-in-the-loop".

Conduct of Experiment - collection of data from on-line and/or off-line simulation.

Data Analysis - analysis of experimental data (plots, recorded parameter values, video tape, audio, observational).

Report Preparation - presentation of results, findings/recommendations in final report form.

In addition to the brief overview of the research process at CAORF, it should be noted that CAORF has the capability to simulate any vessel in any port or area in the world.

Following is a detailed description of the major subsystems which comprise CAORF, which are also illustrated in Figures A-1 and A-2.

ON-LINE SYSTEM HARDWARE

Computerized Image Generator - constructs the computer generated visual images of the surrounding environment.

- Images in full color, are projected onto a cylindrical screen having a radius of 29 feet, subtending 240 degrees horizontal and 24 degrees vertical field of view.

- Shading can be varied, as can illumination from full daylight to moonless night.

- Visibility in the day or night scenarios may also be reduced to simulate any degree of fog or haze.

- The visual scene updates 30 times per second to ensure smooth visual scene motion.

- Perspective is set for the actual bridge height above the waterline of the simulated vessel.

- Subjective motion information is available; there is no capacity for physical motion simulation at this time.

- Twenty dynamic traffic ships are available in the visual scene. Numerous stationary ships are also available.

Ship's Bridge - a simulated ship's bridge, 20 ft. (6.1 m) wide by 14 ft. (4.3 m) deep which contains all equipment and controls normally available on a merchant vessel.

- The equipment responds with realistic accuracy, providing a subject watch officer ("man-in-the-loop") the opportunity to maneuver ownship through a scenario.

- Port and starboard bridge wings, each equipped with gyro repeaters to allow visual bearings to be taken and plotted on a chart.

- Tugboat control console may be added for simulation of a tug wheelhouse.

- The equipment on the bridge can be reconfigured for single or twin screw operation, and includes:

Steering

Gyro steering, hand steering, and NFU steering,
Gyro repeater,
Rudder angle indicator,
Rate of turn indicator,
Steering failure alarms.

Propulsion

Throttle and telegraph engine order (single/twin screw),
RPM indicators,
Bow/Stern thrusters with respective indicators and status lights,
Engine failure alarms.

Ship Motion Indicators

Speed and speed log,
Doppler speed display.

Navigation

2 Collision Avoidance Systems, Radar/ARPA,
Fathometer,
Pelorus - Bridge wing calibrated for parallax,
Wind speed and direction indicators.

Communications

VHF radio,
Intercom,
Sound powered phones,
Ship's whistle,

Sound System

Digitally sampled:

OS engine,
OS whistle,
Environmental sounds,
NavAids sounds.

Central Data Processor - computes ship motion in accordance with maneuvering characteristics and environmental conditions (including currents, channel banks, passing ship effects).

- Models the behavior of all other traffic ships.
- Drives the appropriate bridge indicators (wind, radar, Doppler, etc.)
- Communicates with and controls visual, radar, sound, and situational display subsystems.
- Drives control station indicators.

Radar Signal Generator - synthesizes real-time video signals to stimulate two (2) Plan Position Indicators (PPI's).

- Displays up to 20 moving traffic ships.

Control Station - central location from which the simulator experiment is initialized, controlled, and monitored.

- Traffic ships, assist tugboats, environmental conditions and mechanical failures can be controlled by operators observing the experiment underway.
- All communications between bridge and outside persons are carried out from this station.

Assist Tug Simulation - simulation of up to six (6) assist tugs for use at any point along ownship's hull.

Human Factors Station - remote location for observation of simulator research in progress.

- Unobtrusive observation and data gathering by experimental psychologists may be conducted.
- Video and audio recordings may be made of activities of bridge personnel for playback/evaluation.

OFF-LINE SYSTEM HARDWARE

Fast-Time Simulation - in addition to real-time simulation, CAORF has the capability to perform off-line simulation runs independent of visual displays, wheelhouse, radar or control station operations:

- One-ship fast-time routine,
- Two-ship fast-time routine,
- Fast-time interactive steering system which allows the user to control all steering from a CRT monitor.

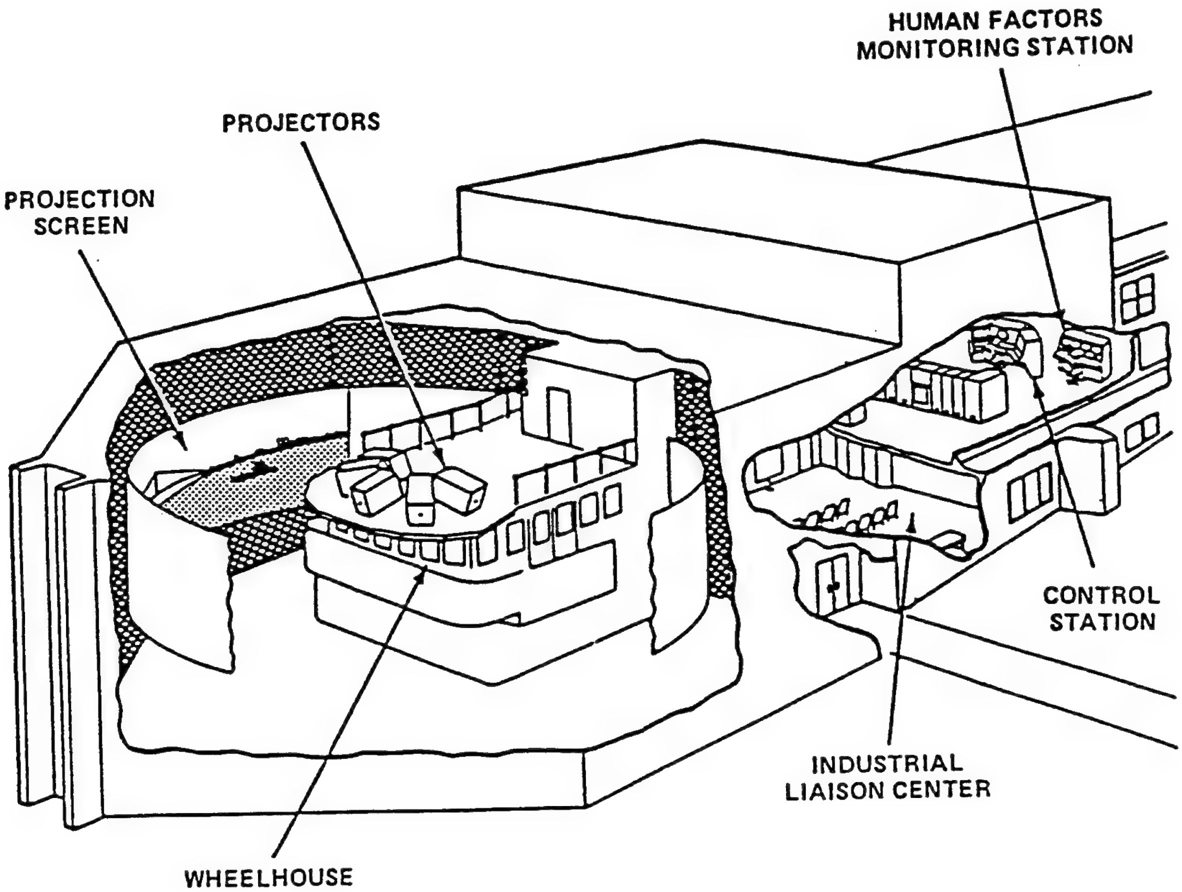


Figure A-1. Cutaway of Computer Aided Operations Research Facility (CAORF) Building

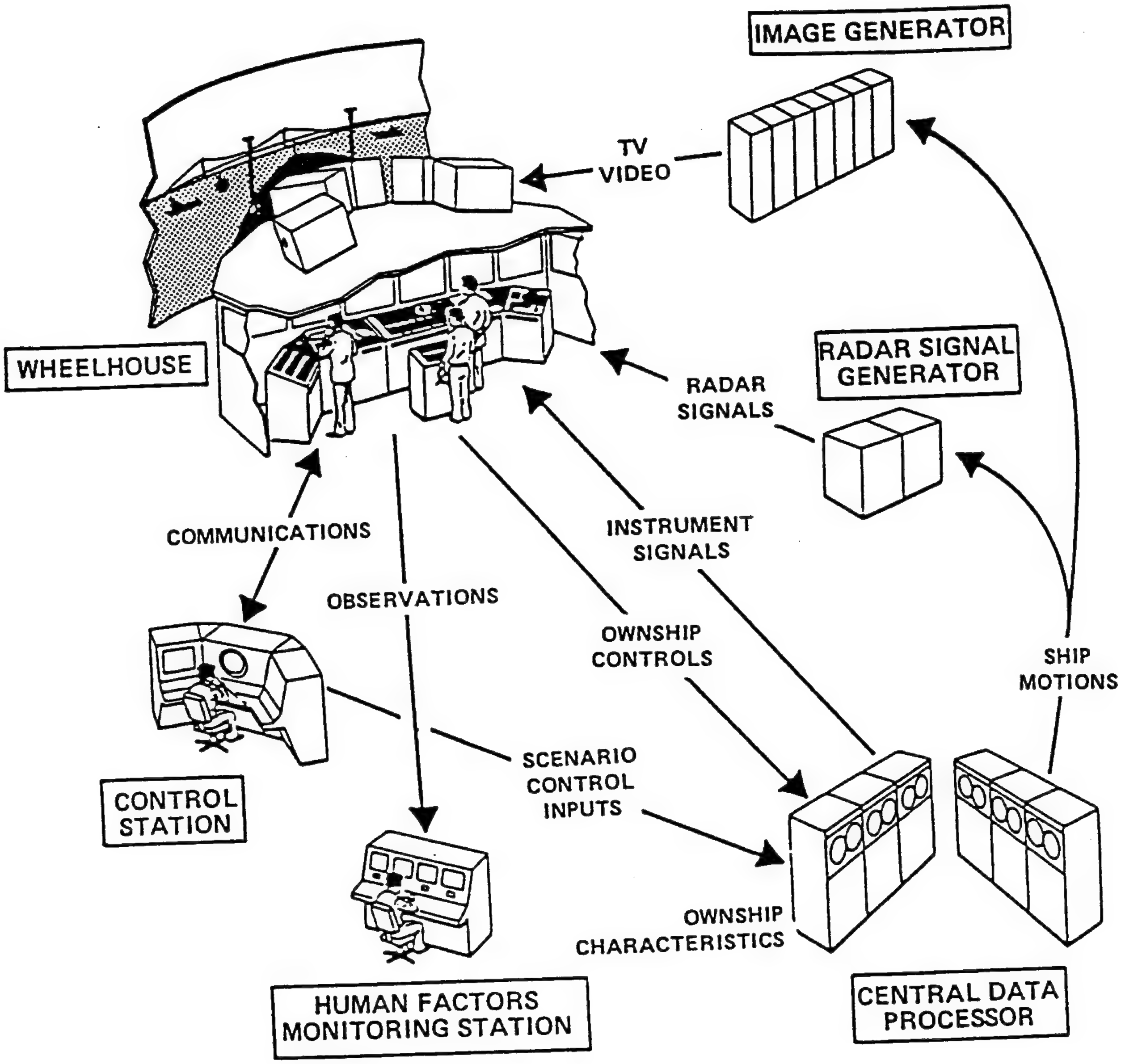


Figure A-2. Major Computer Aided Operations Research Facility (CAORF) Subsystems

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APPENDIX B.0 SUPPLEMENTARY MATERIAL FOR SECTION 2.0 SIMULATION AS A "TEST BED" FOR ECDIS EVALUATION

B.1 DESCRIPTION OF THE COMMERCIAL ECDIS DEVICES

B.1.1 User Interfaces of the Two Devices

From the user's standpoint, each of the two devices basically consisted of a graphic display and an operator's panel for inputting and/or displaying numerical data. The Robertson Marine Systems' Disc Navigation had a single 63.5 centimeter (25 inch) graphic display of the chart, while the Offshore Systems Limited's (OSL) Precision Integrated Navigation System VME had a 48.26 centimeter (19 inch) graphic display that was portioned into a main view and a smaller secondary view of the chart, and a panel of numerical navigation data. The size of the OSL's main chart view, secondary chart view and navigation data panel could be manipulated by choosing one of four setup configurations (described below).

The operator's panel on both devices provided the user with some control over the data presented and the navigational functions implemented. The operator's panel on the Robertson ECDIS was activated with push-button keys, divided into different sections. The main section contained an interactive LCD text display of navigation data, with soft-key push-buttons for accessing several sub-menus of information. Also part of this section was a panel of keys for inputting alphanumeric data. To the left was a panel of keys for turning on/off various layers of chart detail. To the right was a roller ball with three associated keys, one of which enabled access to navigation or planning functions (depending on mode) requiring cursor positioning with the roller ball (described below). To the far right were keys for controlling system activity (e.g., on/off, alarm acknowledge, monitoring or planning mode, and degauss).

The operator's panel on the OSL ECDIS included two electro-luminescence screens (ELS) with finger-touch activation, and a roller ball with three associated buttons. The left touch-screen contained controls for turning on/off the entire system and the radar overlay, and for adjusting the radar gain. In addition, this screen contained keys for manipulating the scale of the primary and secondary charts. The right touch-screen was

divided into three main sections, one containing system information, one for main menu choices, and one for sub-menus. Through the main and sub-menus, the navigation data displayed on the right hand portion of the chart display screen could be customized.

The OSL ECDIS provided a flexible configuration for the chart display, allowing four different layouts on the screen. They were:

- "extended nav" consisting of a large main chart window with a smaller chart window and a text window on the right side of the screen,
- "split screen" which presented two graphic windows of the same size with the text window across the bottom,
- "local nav" which presented one large chart window with text windows on the right, and
- "docking" in which one large chart display filled the screen with no text windows.

The OSL "extended nav" configuration was designated as the default for the experiment and was used by the mariners in all but three (short) instances. The main chart window in the extended nav configuration measures 26.67 cm x 26.67 cm (10.5 inches x 10.5 inches). The scale of each of the two charts on the screen could be manipulated independently by selecting one of 16 values on the separate touch screen. Scales are specified in terms of the geographic distance that was presented vertically in the chart window (e.g., 1/2 nm or 25 nm). Only the main chart window displayed radar and cursor data. A frequent practice was to use the main window for a large scale view of the immediate area and the secondary window for a small scale, "extended" view. To support such a use, the secondary OSL chart window shows an outline of the area covered on the main chart window. As an example, if the larger main chart is scaled to one mile and the smaller secondary chart is scaled to 12 miles, the secondary chart displays a square outline covering a one mile radius from the center. This feature enables the mariner to see at a glance both which portion of the chart is being displayed in the main window, and where he is in the larger area of the entire chart.

B.1.2 Presentation of Electronic Chart Features on the Two Devices

The following paragraphs describe the OSL and Robertson ECDIS devices as each was configured for the experiment. The charted features available on each system are compared, and differences which are important to breadth of coverage of this experiment are highlighted. The features described in this section refer to the monitoring modes of

each device. A description of the specific features and functions available for route planning is beyond the scope of this report.

Each ECDIS had its own set of chart features that were not removable, as well as information that could be turned on or off by the user. The permanently retained features of the Robertson charts included the coastline, various pre-defined depth contours, traffic routing systems, and an indication of the selected scale (part of the LCD text display). In addition, six independent layers of chart data could be added to the graphic display including light markings to show which aids are lighted, danger marks (two levels) to show the location of wrecks and other submerged hazards, depth soundings, grid, buoy symbols, and two levels of text (major place names, and minor place names with aids to navigation characteristics). In addition to brightness and contrast controls, the color of the chart features could be varied by choosing one of four IMO-compliant color palettes to accommodate external lighting conditions.

The permanently retained features of the OSL charts included the coastline, various pre-defined depth contours, and an indication of the selected scale (part of the touch screen panel). Other features that could be turned on or off through a sub-menu included buoy symbols, compass rose, north arrow, and a visible bearing line connecting the ship to the cursor. (Note that the presence or absence of the visible bearing line did not affect the functioning of the cursor as a tool for obtaining ranges and bearings.) The brightness and contrast of the entire screen was adjustable.

Table B-1 below indicates the compliance of each ECDIS with the September 1992 version of the IMO PPS on charted features, as each system was configured for the experiment. In general, the Robertson electronic chart conformed more closely to the 1992 Draft Standards in that it had the "look" of a conventional paper chart, while the OSL electronic chart provided less chart information.

Table B-1. Compliance of ECDIS Devices with IMO PPS

IMO PPS (Sept. 1992)	OSL PINS-VME	ROBERTSON DISC NAVIGATION
DISPLAY BASE		
.1 coastline (high water)	YES	YES
.2 ownship's safety contour, to be selected by the mariner from the depth contours provided by the SENC	NO	PARTIAL The user could specify ship's draft and warning time, and get auditory warning.
.3 indication of isolated underwater dangers of depths less than the safety contour which lie within the safe waters defined by the safety contour	NO	NO
.4 indication of isolated dangers which lie within the safe water defined by the safety contour such as bridges, overhead wires, etc., and including buoys and beacons whether or not these are being used as aids to navigation	NO	NO
.5 traffic routing systems	NO	YES showed traffic separation scheme.
.6 indication of scale, range, orientation and display mode	PARTIAL Scale indicator easily visible on high-lighted touch panel display. No indication of orientation, though only North-up was available.	PARTIAL Digital indication of scale in upper left corner of text display. No indication of orientation, though only North-up was available.
.7 units of depth and height	PARTIAL Units of navig. data were indicated. There are depth contours, but no indication of what depths they refer to.	NO No positive indication, though depth soundings were in meters according to manuf. Units of navig. data were indicated.
STANDARD DISPLAY		
.1 display base		
.2 drying line	NO	YES
.3 indication of fixed and floating aids to navigation	YES red, white or green symbols .	YES
.4 boundaries of fairways, channels, etc.	NO	YES
.5 visual and radar conspicuous features	NO	NO
.6 prohibited and restricted areas	NO	NO
.7 chart scale boundaries	NO Any chart could be scaled from 1/4 nm to 100 nm.	YES Limit defined by chart type (e.g., coastal, harbor).
.8 indication of cautionary notes	NO	NO
SUPPLEMENTAL INFORMATION		
.1 spot soundings	NO	YES Can be turned on/off for whole chart.
.2 submarine cables and pipelines	NO	NO
.3 ferry routes	NO	NO
.4 details of all isolated dangers	NO	NO
.5 details of aids to navigation	NO	YES On/off button. Provides nav-aid characteristics including flash rate and color.
.6 contents of cautionary notes	NO	NO
.7 ENC edition date	NO	NO
.8 geodetic datum	NO	NO
.9 magnetic variation	NO	NO
.10 gradicule	NO	YES On/off button. Both grid and scale bar.
.11 place names	NO	YES On/off button. Two levels available: Major place names and then minor names and nav-aid characteristics (see .5).

B.1.3 Electronic Charts Available

The OSL ECDIS contained three manufacturer digitized charts of the New York area corresponding to Charts 12326 (Approaches to New York, scale 1:80, 000), 12327 (New York Harbor, scale 1:40, 000) and 12334 (lower harbor, scale 1:19, 000). The Robertson ECDIS contained two New York area charts corresponding to Charts 12326 and 12327 and two San Francisco area charts corresponding to Charts 18645 (SF coast, scale 1:100, 000) and 18649 (SF channel through to the Southern anchorages, scale 1: 40,000). The scales chosen by the mariners should be viewed in the context of the areas being transited and the charts that were available.

B.2 SIMULATOR AND SIMULATION MODEL CONFIGURATION

B.2.1 Simulation Geographic Model

Existing simulation models of New York (NY) and San Francisco (SF) harbors and approaches were used as operations areas. Both areas provide high workload, high risk coastal and harbor/harbor approach regions of sufficient complexity and diversity to investigate ECDIS use over a range of conditions. In addition, electronic charts for the NY area were available from both vendors and electronic charts for the SF area were available for the Robertson Disc Navigation System.

The simulation model consisted of several integrated databases that worked in coordination to provide the mariner on the bridge visual, radar, sound, and hydrodynamic environments consistent with the real world and with the electronic charts of the area. The ship's bow, buoys, fixed aids to navigation, bridges, land masses, and cultural features and sounds were represented to the extent necessary to create a realistic, functional, and familiar environment for the mariner.

B.2.2 Ship Response Model

The ship response model is a mathematical representation of a specific ship. It reproduces the ship's maneuvering characteristics, including such factors as the hydrodynamic characteristics, aerodynamic profile, and machinery dynamics. It also

interacts with the simulation data base's representation of currents, banks, bottom, and wind to incorporate these effects into the ship's response. A ship response model of the Lancer class containership was used during the entire experiment. This model has been validated against sea trial data (J.J. Henry Co, Inc. and Systems Control Inc., 1979) and has been used in a number of port design test programs (CAORF Staff, 1992) and in senior mariner training programs (Fritzke and CAORF Staff, 1985).

The Lancer class containership is a medium-sized ship with good handling characteristics and is one with which all experienced mariners would feel comfortable. It has overall length of 217.93 meters (715 ft), a beam of 27.43 meters (90 ft), and was modeled with a 9.14 meter (30 ft) draft and displacement of 30,130 tons. Tables B-2 and B-3 present further data on the vessel's characteristics.

B.2.3 Simulator Bridge

The bridge arrangement used for the duration of the study is shown in Figure B-1. The bridge was configured with the ARPA, engine order telegraph (EOT), ECDIS, and second radar unit in a line at the center of the bridge. The appropriate ECDIS system -- OSL or Robertson -- was installed for a particular scenario. The ECDIS on the bridge was turned off during the interspersed baseline (paper chart) scenarios. The radios, intra-ship communications, whistle controls, and general alarm were along the forward and after bulkheads. The chart table was in the rear on the port side of the bridge, facing forward. A Differential Global Positioning System (DGPS) receiver and fathometer were located behind the chart table in bulkhead mounted shelves. Other bridge equipment present were: gyro-repeaters, RPM and rudder angle indicators, course and rudder angle recorder, and navigation light panel. Port and starboard bridge wings had gyro-repeaters and bearing circles. The steering stand was on the ship's centerline behind the main consoles. (A qualified helmsman was present during the runs.)

This arrangement was designed for the needs of this experiment. The modified cockpit arrangement and centralized control were intended to take full advantage of ECDIS. The mariner could stay at one location just forward of the steering stand, watch the ECDIS or the ARPA, and perform ship-to-ship communications from that spot. Some features of the bridge arrangement were needed to facilitate data collection. The separation of the ECDIS and the ARPA required the mariner to walk between them, making it possible for experimental observers to determine which system the mariner was using at any one time.

The ECDIS location on the starboard side of the bridge allowed the most effective observation by a ceiling mounted camera. The chart table's placement forward of the aft bulkhead both allowed the mariner to look forward while referring the paper chart and made it evident to observers when the mariner left the "conning" station to refer to the paper chart.

B.2.4 Monitoring Capabilities

The mariners' activities on the bridge and important aspects of the simulation were observed by the experimenters from the Human Factors Station (HFS). The entire bridge area was monitored via a network of six low light video cameras and four microphones. Figure B-1 also shows the camera and microphone locations. The radio and intra-ship communications were also monitored. The entire progress of the simulation was displayed on video monitors at the Human Factors Station (HFS). The simulator's Visual Situation Display (VSD) provided a aerial view of the progress of own ship and traffic ships in real-time with aids to navigation, traffic lanes, tracklines, and landmasses displayed. Hard copy printouts of the VSD display were systematically collected for use in scoring the mariners' track recreation during the debriefings. A repeater showing all activities on the ARPA and a monitor showing own ship status (i.e., speed, heading, rudder order/angle, engine revolution per minute, wind, underkeel depth, and bow thruster status) were also located at the HFS.

Table B-2. Lancer Class Vessel Characteristics

M/V ECDIS Principle Dimensions	
LOA	218 m (715 ft)
LBP	204.3 m (670 ft)
Beam	27.4 m (90 ft)
Distance Bridge to Bow	164.6 m (540 ft)
Distance Bridge to Stern	53.4 m (175 ft)
Height of Eye	19.8 m (65 ft)
Mean Draft	9.1 m (30 ft)
Trim	0 (even keel)
Displacement at 30 feet	30,130 LTons

Table B-3. EOT - RPM Speed Table

M/V ECDIS		
ENGINE ORDER	**RPM**	**SPEED**
Full Sea Speed	72	18.5 knots
Full Ahead	48	12.5
Half Ahead	30	7.8
Slow Ahead	20	5.2
Dead Slow Ahead	10	2.6
Dead Slow Astern	10	
Slow Astern	20	
Half Astern	30	
Full Astern	40	

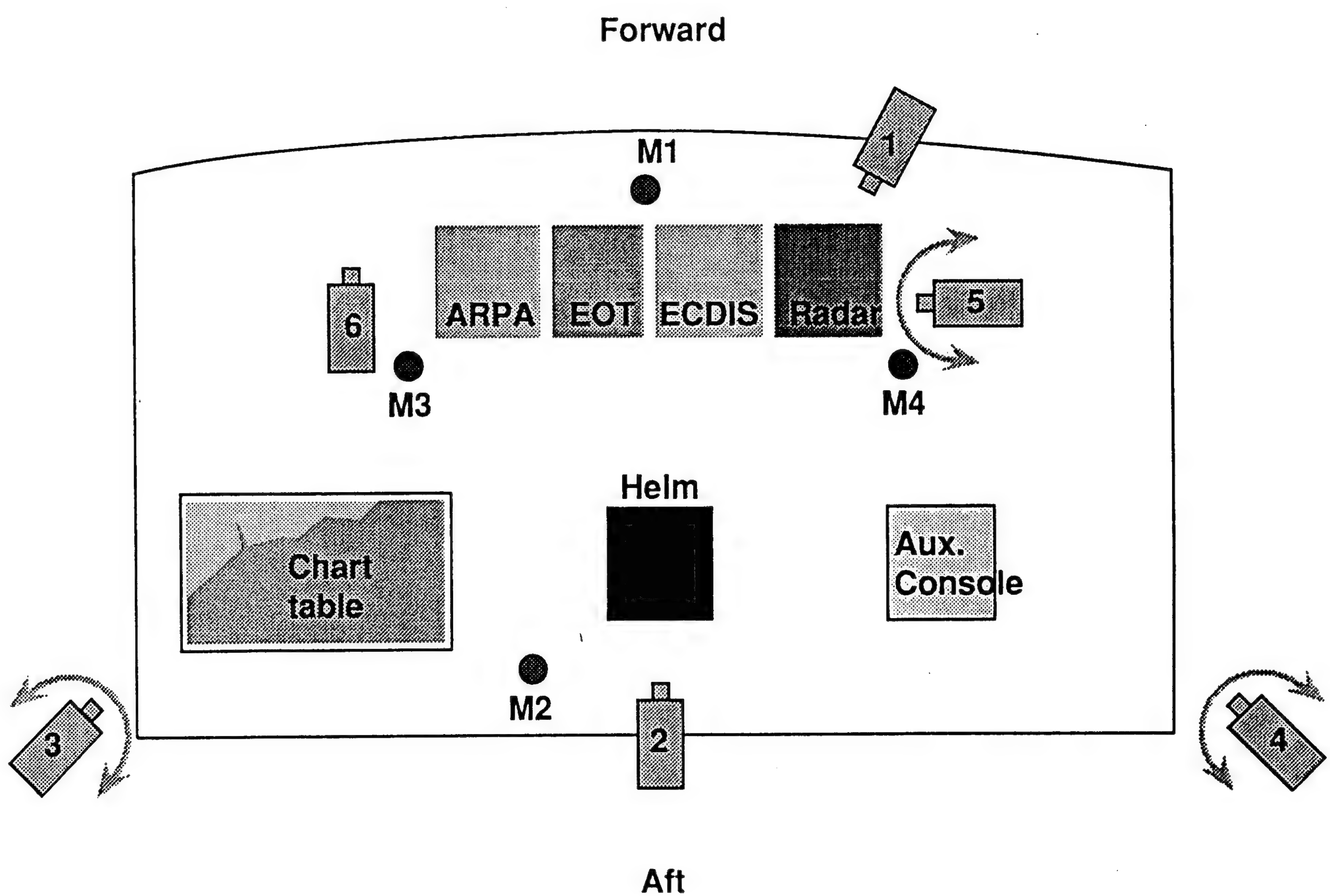


Figure B-1. Arrangement of the MSI/CAORF Bridge for the ECDIS Evaluation

APPENDIX C.0 SUPPLEMENTARY MATERIAL FOR SECTION 3.0 THE EVALUATION PLAN

C.1 POSSIBLE SEQUENCE AND RUN ORDER EFFECTS

The experiment was planned for each participating mariner to experience all nine scenarios. In such a case, the possibility of sequence or run order effects is a consideration. Sequence effects that might be expected to improve performance during a week of repeated runs include learning, practice, or familiarization with the simulator, with each of the ECDIS systems, and with the required bridge management tasks. Effects that might have negative effects on performance include boredom and fatigue. To prevent such biases in measured performance, each mariner experienced the scenarios in a different, pre-planned order.

Because of the experience and comments of mariners who assisted in the preparation of the experiment, some constraints were placed on a strict counter-balancing of order. First, to allow each mariner to learn to operate the ECDIS devices, each mariner ran all the scenarios with one device before switching to the other. (There was training on each device just before the first transit with that device and the first device to be used was alternated among the mariners.) Second, because of the difficulty in manually updating ECDIS when its automatic positioning capability "failed," this mode was presented only after a mariner had completed at least two ECDIS runs with a given device. Third, because of the possibility that the first scenario run by a mariner might suffer from a lack of familiarity with the simulator or with procedures, each scenario appeared in the first position for only one mariner. (This first scenario was after a "familiarization" scenario during which no data were taken.) Lastly, the baseline transits were spaced so that they were in the different harbor from the ECDIS transits before and after them to avoid mariner boredom.

These attempts to avoid bias were successful. On preliminary analysis, none of the quantitative performance measures used showed any correlation with run order. Therefore, order effects were not considered in any subsequent analyses.

C.2 THE PARTICIPANTS: MASTERS AND MATES

Each participant in the study was sent a package of introductory materials prior to arrival at CAORF. The package included a brief description of the study's focus and an orientation to the week's schedule, a user's manual for each ECDIS, a brief discussion of Differential GPS (DGPS), and a Mariner Profile questionnaire. The following paragraphs describe the experience of the participants and is based on their responses to a Mariner Profile questionnaire and any resumes they appended.

Maritime experience. The six participants for the study included four Masters (unlimited license), each with more than 20 years of experience, one Second Mate (two years of experience) whose highest capacity sailed was Third Mate, and one Chief Mate (nine years of experience) whose highest capacity sailed was Second Mate. Three of the four Masters have First Class Pilotage in Prince William Sound, Puget Sound, and San Francisco Bar to the Golden Gate Bridge, respectively. Both Mates also have a 1600 ton Masters endorsement. Five of the mariners sailed six to seven months in the preceding year, and one sailed three months. The participants' present sailing vessels include container ships, roll-on/roll-off freighters, liquefied natural gas (LNG) tankers, and crude carriers, representing companies including Marine Carriers, EXXON, Ahrenkiel, APL, and Energy Transport.

Familiarity with ECDIS and navigation/plotting devices. The average reported level of familiarity with ECDIS of the participants prior to the study was 1.7 on a scale from 1 (unfamiliar) to 5 (very familiar). However, some of the participants indicated that they did have some experience with or exposure to other navigation/plotter type devices. This included extensive experience of one Master with SNA-91, a system that enables the user to digitize chart information and present it on the radar scope, experience of another Master with Trimble Navigraphic Loran and Loran/GPS, and one month of using Sperry ExxBridge aboard ship by a Second Mate.

Familiarity with New York and San Francisco harbors. With the exception of one Master who sailed into and out of New York Harbor 25 times in the previous 12 months, all of the participants sailed into and out of NY once or less in the last 12 months. In addition, two of the Masters and one Mate sailed into or out of San Francisco Harbor six times in the last 12 months, while the rest of the participants didn't sail in SF at all (including the Master with SF Pilotage).

Familiarity with Sperry RASCAR radar. With the exception of two Masters who were unfamiliar with Sperry's RASCAR radar (used on the CAORF bridge), all of the participants indicated that they were moderately familiar with the system.

Familiarity with Global Positioning System (GPS) and differential GPS (DGPS). Prior to the study, the participants' average reported level of familiarity, on a scale from 1 (unfamiliar) to 5 (very familiar), was 3.5 for GPS and 2.0 for DGPS.

Familiarity with shiphandling simulators. All of the participants have had some prior, recent exposure to ship simulation at MSI's Newport, RI facility and/or MSI/CAORF. Some of the participants have also used other simulation facilities such as Marine Institute of Technology and Graduate Studies (MITAGS) in Lithicum Heights, MD and Seaman's Church Institute in New York, NY.

Familiarity with personnel computers. All of the Masters indicated that they use a personal computer almost every day, while the two Mates use a personal computer about once a week.

C.3 THE PARTICIPATING MARINER'S WEEK AT MSI/CAORF

Each mariner spent a full week making both arrivals and departures in New York and San Francisco on the simulator, under a variety of very demanding and realistic conditions, using ECDIS as the primary method of navigation. The performance measures mentioned below are described more fully in Section 4.0. of the Main Report.

Training with the first ECDIS device. At the beginning of each week, the participating mariner received a thorough and focused training session with the particular ECDIS unit they would be using first (either the Robertson or the Offshore Systems units). Since the mariners were not familiar with these specific devices, they were instructed in the use of the features and functions relevant to that device. Figures C-1 through C-3 present summaries of the OSL device manipulation procedures as well as the features and functions available. Figures C-4 through C-6 summarize the corresponding capabilities for the Robertson device.

Familiarization with all components of the experiment. Each mariner was then familiarized with the operations of the full-mission shiphandling simulator and other bridge equipment (such as the operation of the radar/ARPA and the Engine Order Telegraph and the location of radios, telephones, general alarms, and ship's whistle). In addition, he was provided with a description of the ship model to be used, including vessel dimensions and speed/RPM tables (see Tables B-2 and B-3 of Appendix B). A familiarization scenario was then run (inbound New York, coastal to pilot station, clear visibility, no traffic) so that he could "get the feel" of the integration of the ECDIS with the simulator, of the ship model, of the procedures, and of nuances in the visual scenes. During this familiarization, a member of the research staff remained on the bridge to help him if necessary.

Testing on the first ECDIS device. Following the familiarization run, the mariner was asked to perform various functions on the ECDIS and a checklist was used to determine his proficiency and any re-training he might need. When the mariner was deemed proficient in the use of the ECDIS, the experimental scenarios using that device with variations in mode were then run. Figures C-7 and C-8 present the training objectives checklist used to evaluate the mariner's understanding of the two devices.

Experimental runs with the first device. Prior to the start of each experimental run, the mariner was provided with charts of the area, a summary of the visibility conditions, the wind, the currents, and the time of day in which his watch was to start . He was then asked to prepare a detailed passage plan. (ECDIS was not used for this planning, except for one brief exercise with the Robertson device.) During the series of runs with the first experimental ECDIS, he also made one of the no-ECDIS baseline runs.

The second device and the remaining runs. When the series of simulator runs with one device was completed, the ECDIS was changed and another period of training specific to the second device was initiated. The remaining simulator runs with the second ECDIS in all its modes and the remaining baseline scenario were then completed.

Data collection during the runs. Data were collected during route monitoring activities both by the simulation computer and by experimenters at the remote Human Factors Station (HFS). The computer provided automatic recordings of ownship information (such as heading, rudder angle, and down-track and cross-track distance). At the same time from the HFS, video recordings were made of bridge activity and tallies were kept of specific ECDIS feature/function use. "Track-plots" were periodically printed from the Visual

Situation Display to provide another record of the mariner's performance during the transit. In addition, expert evaluation was conducted for a judgment of the mariner's overall navigation/collision avoidance/bridge management performance.

Post-scenario debriefing. At the conclusion of each experimental scenario, a focused debriefing session was conducted, lasting approximately 30-45 minutes. Data were collected from the mariner via rating scales and questionnaires, to assess his own performance on a variety of measures, including situational awareness, operator workload, safety, and specific ECDIS features and functions they used/wanted. In addition, they were afforded the opportunity to discuss any aspects of the specific scenario and/or the simulation in general.

Post-experiment questionnaire. Following the completion of all test scenarios, the mariner's week concluded with an extensive post-experiment debriefing. This questionnaire asked the mariners for their professional opinions and assessments on a wide range of ECDIS related issues, including the overall test program, charted features and functions for safe ECDIS route monitoring, the chart display, the presentation of radar features, and use of ECDIS in the "real world".

C.4 OBSERVATIONS ON TRAINING THE MARINERS IN THE USE OF THE ECDIS SYSTEMS

A number of inter-related training issues can be identified. The first is the operation of the specific device. Initial training with the specific device was essential for all six of the mariners. Because the user interfaces on the two devices were so different from each other, training on the second device was as necessary as training on the first. (Note that several of the mariners also reported interface difficulties with the unfamiliar ARPA on the MSI/CAORF bridge.)

MSI/CAORF staff identified another potential need for training. The pre-experiment questionnaire and subsequent discussions showed that not all of these experienced mariners had meaningful knowledge of, or experience with, DGPS. For the safety of navigation, mariners can not be totally dependent on the reliability and accuracy of DGPS or on built-in safeguards and alarms in ECDIS systems. Training on the nature of DGPS and the device's use of this sensor should be included in any ECDIS training. Some

understanding of the electronic chart is appropriate as well. This is especially important for an ECDIS system that allows a ship's crew to digitize their own charts.

The participating mariners were asked if they felt that any "special training" was needed Five of the six participating mariners expressed the view that experienced mariners should need training only on the specific device to be used. They felt that more general training and certification are not needed. Only one individual expressed the opinion that a certified course to obtain an endorsement was needed.

OSL MENU SUMMARY

MAIN MENU	SUB-MENU	
Radar Display/Gain:		
Chart 1&2:	In/Out (or choose value to adjust scale)	
Markers:	Compass Rose North Arrow Bearing Line	
Charts Alpha:	Prev. Box Next Box Enlarge Vessel X-Track Station Line Tgt Position Cursor	
Position:	Change Positioning Device Adjust Offset Freeze Position Plan Position Log	 TrackBall Adjust Set Offset to 0.
Layouts:	Docking Local Nav. Extended Nav. Split Screen	
Units:	Coordinate Distance Speed	
Lines:	Edit Lines Change X-Track	Display Set Change Set Name Select Set Color Reverse Direction Delete line Add line Lay Waypoint Attach to Waypoint
Stations Radar:	Drop Target Test Pattern Trigger Calibrate Azimuth Calibrate Gyro Delay	

Figure C-1. OSL Menu Summary

OSL NAVIGATION SUMMARY

1. Alpha Boxes
   A. Select **ALPHA** from the main menu.
   B. Current box is highlighted in red. The contents of that box are highlighted on submenu.

2. To change CHART and CHART SCALE
   A. Select **CHART** from the main menu. Then select the number of the chart you want from the chart menu (Note: make sure correctstation file is displayed - go to **STATION** on main menu)
   B. To change chart scale, select the desired scale from the control grids marked **CHART 1** or **CHART 2** (Note: Chart 2 may not be present depending on which Layout is chosen).

3. To enable/disable RADAR OVERLAY
   A. Press the box on control panal marked **RADAR.** Radar overlay is turned on when box is highlighted. Press again to Disable.
   B. Increase/Decrease radar gain by sliding finger along **RADAR GAIN**

4. Chart Attributes
   A. To turn on/off chart attributes, press **MARKERS** on main menu. Then select attributes you want (COMPASS ROSE, NORTH ARROW, BEARING LINE).
   B. To change chart layout, select **LAYOUT** from main menu, then choose your desired layout (DOCKING, LOCAL NAV, EXTENDED NAV, SPLIT SCREEN)

5. Manually Adjust Ownship Position
   A. select **POSITION** from main menu, then select **ADJUST OFFSET**. To place the ship where the cursor currently is, select **MOVE TRACKBALL TO ADJUST.** To undo, select **SET OFFSET TO 0.**

6. To Acquire Radar Targets
   A. Place cursor over target to be acquired. Press the middle button on trackball panel to lock on.
   B. Target information will be displayed in TARGET POSITION box.
   C. To drop an acquired target, select **RADAR** from main menu, then select **DROP TARGET**

7. Take RANGE and BEARING
   A. Place cursor over selected target. **RANGE** and **BEARING** from ownship are displayed in ALPHA BOX (CURSOR).

Figure C-2. OSL Navigation Summary

OSL FEATURES AND FUNCTIONS

BUTTON	FUNCTION
Radar Display:	The radar display will be overlayed on the screen when this is pressed.
Radar Gain	By moving your finger from left to right on the bar, the radar gain is increased, and it is decreased by sliding your finger from right to left.
Chart 1&2	These control grids, are used to select the scale which you desire for the two chart displays. Chart one is the primary chart on the left, and chart two is the chart on the right. This chart may not be present, depending on the layout that is being used.
In	Hitting In, will zoom in one spot on the scale, each time it is pressed.
Out	Pressing Out, zooms out in the same fashion as In works.
Markers	**Compass Rose**: Selecting this will light a compass rose on the primary chart. **North Arrow**: The North arrow will light up in the top right corner of the primary chart, when this is hit. **Bearing Line:** The bearing line, is a solid line from the own ship symbol to the cursor, and works much the same as an EBL.
Charts	Select the chart you desire to use, just as you would select a paper chart. Then hit the button that has the correct chart number on it.
Alpha	This control grid is used to select what is displayed in the individual information boxes. They are found either on the right side of the screen, or on the bottom of the screen, depending on the layout that has been selected. A red outline will be around the box that is currently ready for changing. **Prev. Box:** This button moves the red outline back to the previous box. **Next Box:** Hit next box, and the next box over will be outlined, for an information update. **Enlarge:** Enlarge, will make the important information in the selected box larger, and easier to read. **Vessel:** The vessel information selection, will give the position of the ship. **X-Track:** This information box gives cross track information. **Station:** Station gives buoy information, for a selected buoy or mark. **Line:** Line gives waypoint information, including position, course to steer, and distance between waypoints. **Tgt Position:** Target position, displays ARPA information on selected radar targets. **Cursor:** The cursor information box gives range and bearing from ship, along with Lat. and Long. of cursor position.
Position	**Change Position Device:** Selects which navigation device you desire to use to update your position. <u>For CAORF, select NMEA 0183, the other choices will not work.</u>

Figure C-3. OSL Features and Functions

	Adjust Offset: To place the ship where the cursor presently is, hit **Move Trackball to adjust**, and the ship will move to that spot. To undo hit **Set Offset to 0.** **Freeze Position Plan**: Freezes position, for easier writing down of information. **Playback/Clear Position log:** Will be used in the future, but <u>currently is not functioning.</u>
Layouts	**Docking:** This layout of the OSL will display Chart one only on the screen, without any information boxes. **Local Nav.:** Again this display will only have the primary chart, but it will have seven information boxes on the right side of the screen. **Extended Nav.:** The primary chart will be displayed along with a small chart #2 in the top right corner, with four information boxes underneath. **Split Screen:** The split screen layout will display charts one and two, side by side, and of equal size, with six information boxes underneath.
Units	**Coordinate:** Choose from Lat. and Long., Universal Time Meridian, Rectangular coordinates, and Polar coordinates. **Distance:** Select distance in Meters, Feet, Cables, Miles (statute), and Nautical Miles. **Speed:** Ships speed can be either in Knots, meters per second, or Kilometers per hour.
Lines	**Edit Lines:** Edits and creates route plan that you select. **Display Set** must be lit in order for you to see the route on the screen. **Change Set Name** is used to change the name of a route plan. **Select Set Color** lets you choose the color of the lines of your plan. **Reverse Set Direction** will give the reciprocal courses for any plan. **Delete line** erases the line that the cursor is on. **Add line** creates a waypoint, by putting the cursor in the desired spot, then hitting Lay Waypoint, then go back to the previous waypoint and hit Attach to Existing Waypoint and a line will connect the two. **Change X-Track:** Choose which route plan you desire to use with this function.
Stations	Stations are the buoy files, in order to display the correct buoys for the chart being used, <u>use the last three digits of your chart number and select all the stations with that number.</u> There is one station for each color group of buoys.
Radar	**Drop Target:** Drops the acquired target from the ARPA. **Test Pattern:** Gives a radar test pattern similar to an archery target. **Trigger Calibrate:** <u>Do not touch, or radar overlay will be incorrect.</u> **Azimuth Calibrate:** Same as above. **Gyro Delay:** Same as above.

Figure C-3. OSL Features and Functions (cont.)

ROBERTSON MENU SUMMARY FOR ROUTE MONITORING

CURSOR FUNCTIONS IN MONITOR MODE:

No Cursor	Nav-Lines	ARPA Targets
Manual Center	Range/Bearing	DR-Reset

MAIN MENU	SUB-MENU	
Chart	New Scale.................. True Motion Relative Motion Auto Center	Select Level/Scale
Ship	Manual Input.................. Vector On/Off Vector Time Track Time On/Off Labels On/Off	Input Speed Input Course Input Drift Input Set Reset DR-Pos
Echo Sounder	Open Log..................... Delete Backup Distance Draft	Create Log
ANTS	Enable ANTS Change Route POS CTS XTE WOW	
ARPA	Enable Targets................	Vectors On/Off True/Relative
Nav	Dead Reckoning Decca Transit Loran-C GPS KF	
Setup	Bright Control................ Bright Palette Normal Palette Dusk Palette Night Palette Set Clock Ground Time Update System	Contrast-Text Brightness-Text Contrast-Graphic Keyboard Backlight

Figure C-4. Robertson Menu Summary for Route Monitoring

ROBERTSON NAVIGATION SUMMARY

FOR CURSOR FUNCTIONS IN THE **MONITOR** MODE, USE THE **FUNCTION** KEY TO SELECT OPTIONS

1. **NO CURSOR:** Used to turn the cursor OFF

2. **NAV-LINES:** Used to measure distance between two points.

3. **ARPA TARGETS :** Used to display information about a target
   To display target information: Place the cursor over the selected target, press SET key once, and that target information will be displayed in upper right of text screen

4. **MANUAL CENTER:** Used to move the chart with vessel to the cursor position. Move the cursor to the area on chart wanted as vessel position and press **SET** Key once. Chart will be redrawn with vessel placed at the cursor's position. **NOTE:** THE **CURSOR** KEY WILL MOVE THE CURSOR TO THE CENTER OF THE CHART.

5. **RANGE/BEARING:** Used to measure distance from ownship to other objects (i.e., aids to navigation, land). Using the trackball, move the cursor to a selected object. That object's range and bearing from ownship will be displayed on text screen

6. **DR-RESET:** Used to manually re-set ownship's Dead Reckoning position

MENU FUNCTIONS IN MONITOR MODE:

1. **CHART**: This function is used if chart scale or center is changed.
   NEW SCALE: Choose new LEVEL or SCALE
   TRUE MOTION: Displays ownship movement on FIXED chart (vessel speed determines when chart is redrawn).
   RELATIVE MOTION: Displays FIXED vessel while chart moves
   AUTO CENTER: System decides where chart center will be.

2. **SHIP:** Used for selection and input of navigational data.
   VECTOR ON/OFF: Displays a vector from ownship
   TRACK TIME: Records the time between recorded track positions
   LABELS ON/OFF: Will display the time vessel passed recorded track positions
   MANUAL INPUT: Allows manual input of vessel SPEED, COURSE, DRIFT, SET. RESET DR-POS is used to manually update DR position (lat/long).

3. **ECHO SOUNDER**: If an echo sounder is interfaced with ECDIS, it is possible to log signals from this to a file. THIS FUNCTION DOES NOT CURRENTLY WORK.

Figure C-5. Robertson Navigation Summary

4. **ANTS**: **ENABLE ANTS**: Allows for automatic track steering along a pre-planned route. Alarms are sounded when tolerance parameters are exceeded.
CHANGE ROUTE: Allows you to change selected route
POS: Position difference tolerance
CTS: Off-course tolerance
XTE: Cross-track tolerance
WOW: Wheel over warning time - alarm sounds to initiate course changes

5. **ARPA:** If an ARPA radar is interfaced with ECDIS, both fixed and moving targets will be displayed.
ENABLE TARGETS: Will allow acquired targets to be displayed
VECTORS ON/OFF: Turns on/off target heading vector
TRUE/RELATIVE: Shows either true or relative target motion

6. **NAV:** Allows you to select active navigational device: DR, DECCA, TRANSIT, LORAN-C, GPS. NOTE: in the event of losing navigational data from selected receiver, ECDIS will switch to DR position.

7. **SETUP:** Allows you to change the brightness of the chart display (Bright, Normal, Dusk, Night), contrast and brightness of text display, and to update system. If date or time in text display is incorrect, can be edited by using the SET CLOCK key.

Figure C-5. Robertson Navigation Summary (cont.)

ROBERTSON FEATURES/FUNCTIONS

BUTTON	FUNCTION
Beacon	Creates an overlay for lighted navigation aids, using a yellow symbol.
Buoy	Turns an overlay of buoys on and off.
Marks	First depression of the button will show an overlay of charted wrecks, the second will add on an overlay of pilings.
Depth	Activates depth display in meters from chart datum.
Text	First overlay puts names of geographical areas up, and the second overlay writes information for the navigation aids.
Grid	Displays a Latitude and Longitude grid.
Alarm	By pushing the alarm button, you can shut off any alarm that may have been activated. Active alarms will be flashing on the right side of the menu screen.
Reset	Resets chart attributes to IMO Standards.
Monitor	Pushing this button puts the Ecdis in monitor mode, where ships current position is displayed.
Plan	Selecting plan mode, brings up menus that are used to set up waypoints and plan routes.
On	Turns the Robertson Disc Navigation System on.
Off	There are two off buttons, to turn the machine off, push both buttons at the same time, and wait five seconds.
Set	Depending on what function is currently up on the system, the set key, used in conjunction with the rollerball, can be used to set certain aspects, such as waypoints and navlines.
Cursor	The cursor key, depending on current function, will usually center the cursor in the middle of the screen.
Function	Pushing the function button will highlight and select the desired function from the top of the text screen.
Numbers and Letters keypad	These buttons are used to enter numbers and letters. To get the letter C, for example, push the A/B/C button once for A, twice for B, and three times for C.
Esc	The escape key will let you go back one screen from the present screen, and is usually the only way to exit from one of the menus.
B.S	This is the back space key, which allows you to go back a space when entering information from the number and letter keypad.
Enter	Push the enter button when you have finished inputting information from the number and letters keypad.
Trackball	Use the trackball to move the cursor on the screen.

Figure C-6. Robertson Features and Functions

OSL TRAINING OBJECTIVES FOR ROUTE MONITORING

Use ECDIS to monitor vessel's progress effectively using available features/functions.	**1st Try**	**2nd Try**	**Comments**
• Demonstrate knowlege of digital readout information available (identify contents of alpha boxes)			
• Demonstrate knowlege of charts in system. Change chart/chart scale, buoy and station files			
• Demonstrate ability to enable/disable radar overlay; increase/decrease radar gain			
• Demonstrate ability to acquire and track radar targets			
• Demonstrate ability to turn on/off EC attributes (compass rose, North arrow, bearing lines).			
• Manually adjust vessel's position with radar overlay			
• Change screen layouts of electronic chart			
Perform traditional position checking with ECDIS.			
• Use ECDIS to take range/bearing.			
• Select a target and display vessel's range and bearing to it			

ASSESSMENT
1: Need to re-train **2: Satisfactory (found solution with some trial and error)** **3: Excellent (found solution immediately)**

Figure C-7. Checklist for OSL Training Evaluation

ROBERTSON TRAINING OBJECTIVES FOR ROUTE MONITORING

Use ECDIS to monitor vessel's progress effectively using available features/functions	1st Try	2nd Try	Comments
• Demonstrate knowlege of digital readout information available			
• Change charts and chart scales			
• Set chart motion to desired setting (true or relative)			
• Set chart center to desired (autocenter or manual center offset)			
• Respond to appropriate alarm warnings			
• Display appropriate color palette for time of day			
• Invoke track history with time labels			
• Turn on/off chart features (buoys, beacons, etc.) and Reset to minimum display content			
• Use numeric keypad to input any necessary digital information (e.g., lat/long) and to backspace			
•Enable/disable ANTS			
Perform traditional position checking with ECDIS			
• Use ECDIS to take range and bearing			
• Use Nav-lines			
Demonstrate ability to cope with DGPS failure.			
• Check for active navigational device			
• Adjust vessel's position on EC based on independent position fixing.			
• Manually update vessel's course, speed, set, drift, and position (via lat/long).			

ASSESSMENT
1: Need to re-train **2: Satisfactory (found solution with some trial and error)** **3: Excellent (found solution immediately)**

Figure C-8. Checklist for Robertson Training Evaluation

APPENDIX D.0 SUPPLEMENTARY MATERIAL FOR SECTION 4.0 PERFORMANCE MEASURES

D.1 WORKLOAD MEASUREMENT TOOLS

The mariner's experience of workload was evaluated using the NASA-TLX (Task Load Index) subjective rating scale technique (Hart and Staveland, 1988). The NASA-TLX subjective rating scales were validated and refined over a number of years for several experimental tasks ranging from simple cognitive and manual control tasks to supervisory control tasks and aircraft simulation (Hart and Staveland, 1988). Weighted workload scores for the different tasks were found to correlate highly with objective measurements relevant to each task, although certain of the dimensions contributed more to the overall scores, depending on the nature of the task as would be expected (i.e., certain dimensions were judged to be more important for certain tasks). In addition, statistically significant differences in an objective measure of task performance often coincided with significant difference in the workload scores.

Six workload components are rated in the NASA-TLX workload measurement technique. Figure D-1 presents the definitions for each, and Figure D-2 presents the actual ratings scales used for the study. To compute the workload score, each dimension was weighted using a procedure described in Figure D-3. Note that separate ratings were obtained for navigation, collision avoidance, and bridge management. The breakdown given to the mariner of the types of tasks falling into each category is presented in Figure D-4. Finally, each mariner was asked to describe scenario events that produced very high levels of workload or stress, using the "Event Workload" form given in Figure D-5. The main workload analyses are discussed in the main report, as are comments made by the mariners.

D.2 THE MEASUREMENT OF SITUATIONAL AWARENESS

The situational awareness measurement procedure used in this study was adapted from Aretz (1989) and centered around a series of three or four chartlets per scenario which showed the coastline, aids-to-navigation arrangement, and planned route for the area just transited. One chartlet had a relatively small scale and showed the entire route, while the other chartlets showed segments of the route at a larger scale. The mariner first drew in the path of the vessel (from memory) with respect to the planned trackline, using the

larger scale chartlets. He was encouraged to discuss his progress along the route, which often provided insight into his actions , and which were recorded by the experimenter.

The concept of situational awareness was then discussed with the mariner. This discussion focused on a set of clues or warning signs that may indicate a loss of situational awareness, which were identified by Schwartz (1989) in relation to aircraft flight and adapted for use in this study. These clues include ambiguity, distraction, confusion, improper lookout or trackkeeping, failure to comply with passage plan, and violation of basic rules or procedures including communications protocol.

The mariner was then given a situational awareness rating scale ranging from 1 (very low) to 5 (very high). Using the smallest scale chartlet, he drew hatch marks to divide the transit into as many sections as necessary to reflect his changes in situational awareness, and assigned a one to five rating to each section. The rating scale and a sample chartlet are presented in Figures D-6 and D-7, respectively. The percent of total transit distance (transits placed end to end and distances summed) the mariner reported spending at each of the five levels of awareness was compared across bridge conditions. These data are presented in Table D-1, and show that in the ECDIS with Automatic Positioning scenarios (Scenarios 1, 2, 4, 5, and 7) the mariners reported spending a total of 78.46 percent of the transit distance at an awareness levels of four or five, but only 67.49 percent at levels four or five in the Conventional Bridge scenarios (Scenarios 8 and 9). Moreover, they reported spending only 53.58 percent of the total transit distance at levels four or five in the ECDIS without Automatic Positioning scenarios (Scenarios 3 and 6). Thus, these data show a generally increased reported level of situational awareness with a functioning ECDIS on the bridge. Further statistical analyses were not performed.

WORKLOAD
RATING SCALE DEFINITIONS

MENTAL DEMAND	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
PHYSICAL DEMAND	How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
TIME DEMAND	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
OWN PERFORMANCE	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
OVERALL EFFORT	How hard did you have to work (mentally and physically) to accomplish your level of performance?
FRUSTRATION LEVEL	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

Figure D-1. NASA-TLX Workload Rating Scale Definitions

MARINER #_______ RUN # _______ SCENARIO #_______

WORKLOAD RATINGS

1. During your last transit, what percentage of your time was spent on navigation, collision avoidance, and bridge management tasks?

NAVIGATION	COLLISION AVOIDANCE	BRIDGE MANAGEMENT
%	%	%

2. Place an "X" on each of the six scales to indicate your experience of navigation tasks during your last transit.

FOR NAVIGATION TASKS:

MENTAL DEMAND	LOW	├─┼─┼─┼─┼─┼─┼─┼─┼─┼─┤	HIGH
PHYSICAL DEMAND	LOW	├─┼─┼─┼─┼─┼─┼─┼─┼─┼─┤	HIGH
TIME DEMAND	LOW	├─┼─┼─┼─┼─┼─┼─┼─┼─┼─┤	HIGH
OWN PERFORMANCE	GOOD	├─┼─┼─┼─┼─┼─┼─┼─┼─┼─┤	POOR
OVERALL EFFORT	LOW	├─┼─┼─┼─┼─┼─┼─┼─┼─┼─┤	HIGH
FRUSTRATION LEVEL	LOW	├─┼─┼─┼─┼─┼─┼─┼─┼─┼─┤	HIGH

Figure D-2. Workload Rating Scale Questionnaire

MARINER #_______ RUN # _______ SCENARIO #_______

3. Place an "X" on each of the six scales to indicate your experience of collision avoidance tasks during your last transit.

FOR COLLISION AVOIDANCE TASKS:

MENTAL DEMAND	LOW		HIGH
PHYSICAL DEMAND	LOW		HIGH
TIME DEMAND	LOW		HIGH
OWN PERFORMANCE	GOOD		POOR
OVERALL EFFORT	LOW		HIGH
FRUSTRATION LEVEL	LOW		HIGH

4. Place an "X" on each of the six scales to indicate your experience of bridge management tasks during your last transit.

FOR BRIDGE MANAGEMENT TASKS:

MENTAL DEMAND	LOW		HIGH
PHYSICAL DEMAND	LOW		HIGH
TIME DEMAND	LOW		HIGH
OWN PERFORMANCE	GOOD		POOR
OVERALL EFFORT	LOW		HIGH
FRUSTRATION LEVEL	LOW		HIGH

Figure D-2. Workload Rating Scale Questionnaire (cont.)

Sources of Workload Comparisons

Instructions: For each of the following pairs of rating scale titles, circle the member of each pair you feel was the more important contributor to your experience of workload during navigation (either with the ECDIS or paper chart).

Overall Effort / Own Performance

Time Demand / Overall Effort

Own Performance / Frustration

Physical Demand / Own Performance

Frustration / Overall Effort

Performance / Time Demand

Mental Demand / Physical Demand

Frustration / Mental Demand

Time Demand / Frustration

Physical Demand / Frustration

Physical Demand / Time Demand

Time Demand / Mental Demand

Own Performance/ Mental Demand

Mental Demand/ Overall Effort

Overall Effort/ Physical Demand

FOR USE BY STAFF

SCALE TITLE	TALLY	WEIGHT
MENTAL DEMAND		
PHYSICAL DEMAND		
TIME DEMAND		
OWN PERFORMANCE		
OVERALL EFFORT		
FRUSTRATION		

Total Count= _________

NASA-TLX Weighting Procedure

To determine the overall workload score for each of the three sets of ratings per scenario (navigation, collision avoidance, and bridge management), each dimension is weighted in terms of its relative importance to the individual's experience of workload. At the end of the week when both devices had been used and at least one of the baseline scenarios was completed, the mariner made the above workload comparisons. He was instructed to circle one member of each of the 15 pairs shown above to indicate which of the dimensions was the more important contributor to his experience of workload. The frequency with which each dimension was chosen (0 - 5 times) then served as that dimensions weight to be applied to the workload score. One set of workload dimension weights was obtained from each mariner, and applied to all three sets of workload scores, producing an overall workload score for each of the three task categories.

Figure D-3. Workload Comparisons and Weighting Procedure

GUIDE TO BRIDGE TASK BREAKDOWN

NAVIGATION	COLLISION AVOIDANCE	BRIDGE MANAGEMENT
1. Track monitoring a. Position determination b. Awareness of vessel's position relative to aids to navig., channels, dangers to navig.	1. Maintain efficient lookout: visual, aural, & radar/ARPA	1. Integration of engineroom & other dept. activities relative to safe navigation. (preparations for pilot, anchoring, docking, etc.
	2. Monitor traffic for risk of collision and take appropriate actions to avoid close quarters situations.	2. Maintain logs, other administrative duties.
2. Control of course/speed	3. Intership (VHF) Communications	3. Ship to shore and Intraship Communications
3. Knowledge of state of tides, currents, weather conditions affecting navigation.		
4. Monitor passage plan for required course changes & other actions.		

Figure D-4. Mariner's Guide to Bridge Task Breakdown

MARINER #_______ RUN # _______ SCENARIO #_______

EVENT WORKLOAD RATINGS

1. In your judgement, what event(s) during your last transit produced the greatest workload level? Please describe one event and the way you handled it in the space provided below. Use a separate "Event Workload Ratings' form to describe each other event.

2. Place an "X" on each of the six scales to indicate your experience during this event.

MENTAL DEMAND	LOW	HIGH
PHYSICAL DEMAND	LOW	HIGH
TIME DEMAND	LOW	HIGH
OWN PERFORMANCE	GOOD	POOR
OVERALL EFFORT	LOW	HIGH
FRUSTRATION LEVEL	LOW	HIGH

3. Please rate your level of navigational safety during this event:

1	2	3	4	5
VERY SAFE				HIGH RISK

4. How do you think the ECDIS influenced your performance during this event?

Figure D-5. Event Workload Rating Scale Questionnaire

Table D-1. Percent of total transit distance across all mariners spent at each level of reported situational awareness.

	Situational Awareness Level				
Bridge Condition	5 highest	4	3	2	1 lowest
ECDIS w/ Auto Update	33.94	44.52	14.94	5.92	0.67
Conventional Bridge	32.5	35.0	19.72	8.83	3.96
ECDIS w/ Manual Update	23.21	30.38	29.61	16.81	0.0

In addition to examining the length of the transits the mariners reported spending at each level of situational awareness, these ratings were used in a correlation analysis with path re-creation errors. The mariner's hand drawn path of the vessel was visually compared with the actual path of the vessel as recorded in Visual Situation Display (VSD) plots, including both his left/right placement of own ship with respect to the planned trackline, and his placement of course changes in relation to actual course changes. This analysis was chosen because it was hypothesized that the errors made in re-creating the ship's path would tend to be located in sections of the transit where the mariner indicated a lower level of situational awareness. This analysis can be interpreted as an estimate of the mariner's level of situational awareness. In general, the average number of path re-creation errors was fairly small and the variability was high. There was an average of 4.5 errors (SD = 1.72) for the Conventional Bridge scenarios, an average of 2.54 errors (SD = 2.18) for the ECDIS with Automatic Positioning scenarios, and an average of 4.56 errors (SD = 2.19) for the ECDIS without Automatic Positioning scenarios. Overall, a very small negative correlation was found which indicated that a larger number of path re-creation errors was slightly associated with lower levels of reported situational awareness at the location of the error, and the statistical significance of this correlation is only marginal (Correl. = - 0.126, $p < 0.12$).

This correlation was examined further by breaking up the transits into segments corresponding to the legs given in Question 4 of each post-scenario questionnaire (This question asked the mariner to indicate both his primary and secondary method of navigation for each leg of the transit.). For each transit leg, then, there was an indicated primary method of navigation, a situational awareness rating, and some number of associated path re-creation errors (zero or more). The relation between path re-creation

SITUATIONAL AWARENESS RATING SCALE AND SAMPLE CHARTLETS

Situational awareness is defined as an accurate perception of the factors and conditions that effect the vessel and the bridge team during a specific period of time. In other words, you know what is going on around you. A high level of situational awareness yields a decreased exposure to risk.

We request that you rate your situational awareness over the length of the last transit. To assist you in the evaluation of your situational awareness, please note the following indicators or warning signs of a loss of situational awareness.

> APPARENT AMBIGUITY - two or more independent sources of information did not agree.
>
> DISTRACTION - you got completely focused on one item or event and excluded all others.
>
> CONFUSION - you became confused and anxious about a particular situation. You felt that you were losing control of the vessel.
>
> IMPROPER LOOKOUT OR TRACKEEPING - (as a result of DISTRACTION) you failed to keep a proper lookout, lost track of where the vessel was relative to dangers or traffic.
>
> FAILURE TO COMPLY WITH PASSAGE PLAN - you failed to meet ETA's, planned speeds, make course changes on time, got too far off track or other goals set forth in passage plan.
>
> VIOLATED BASIC RULES - failed to adhere to the rules of the road, did not observe proper communications procedures, failed to call vessels .before traffic encounters

Please rate your situational awareness (SA) using the procedure described below.

First draw in your trackline to show the path of the vessel throughout the duration of the transit on the larger scale chartlets. Then, assign a rating (using the scale below) to the different portions of the transit on the small scale chartlet. You may divide the transit into as many sections as necessary to accurately reflect the changes in your situational awareness.

1	2	3	4	5
very low SA				very high SA

Figure D-6. Situational Awareness Definition and Rating Scale

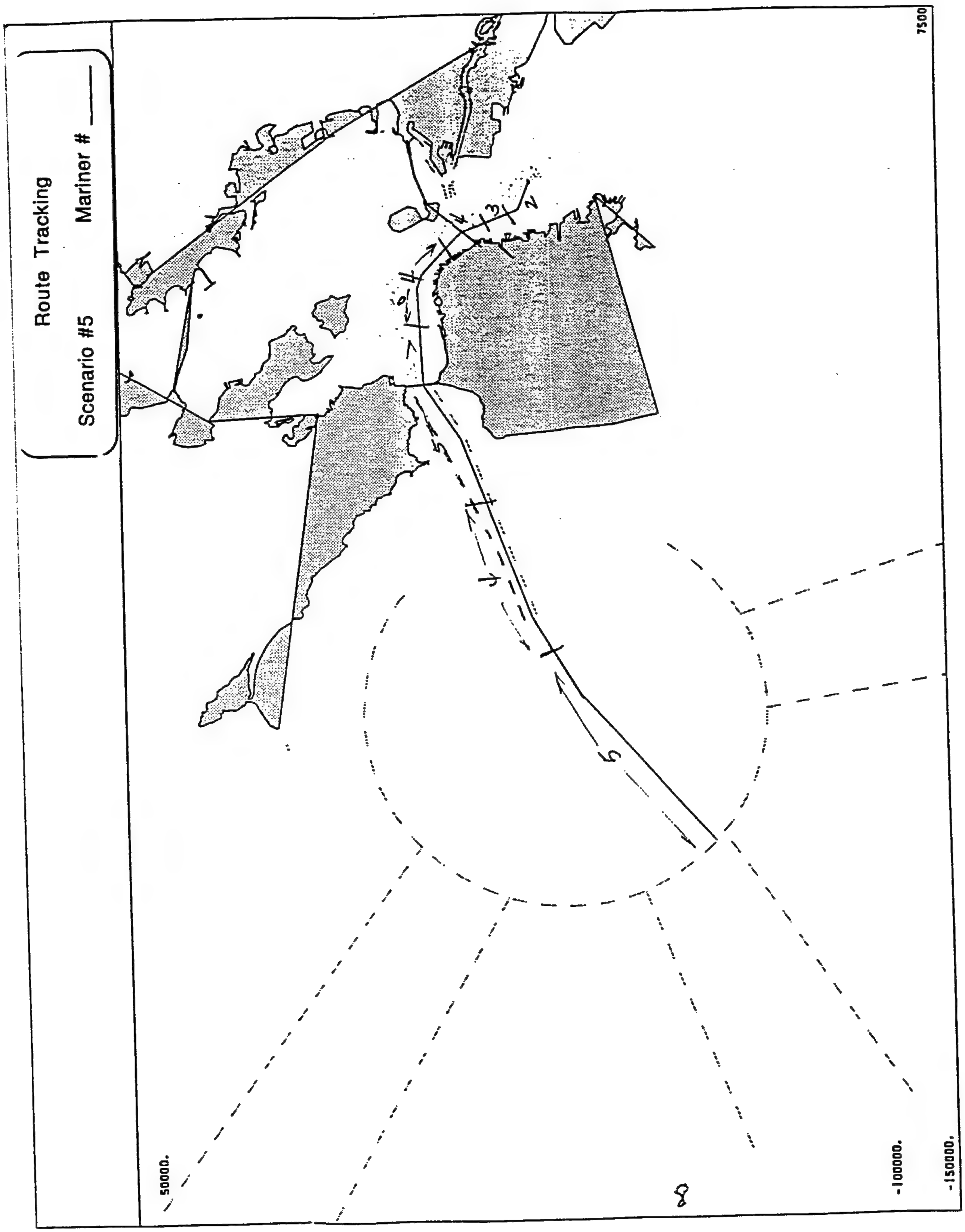


Figure D-7. Sample Chartlet for Indicating Level of Situational Awareness

errors and reported level of situational awareness for those segments of the transits in which the ECDIS was used as the primary method of navigation showed a significant though small correlation (Correl. = - 0.244, $p < 0.04$). That is, while the average number of path re-creation errors was similar regardless of the reported primary method of navigation (i.e., paper chart, visual, radar/ARPA or ECDIS), when ECDIS was the primary navigation method mariners tended to rate their level of situational awareness as lower in the same segments in which they made path re-creation errors. Thus, while this method of predicting the mariner's reported level of situational awareness from the number of path re-creation errors made shows some promise, it needs further testing and refinement to be really useful.

D.3 EXPERIMENTAL OBSERVER'S RATINGS OF MARINER ERRORS

To enable more objective and reliable scoring, the Experimental Observer had available a time history for each scenario which listed the events that comprised each scenario in their probable order (and time) of occurrence. The observer recorded the errors made by each mariner on a set of structured tally sheets which listed the most probable errors for each type of event.

The Observer for all of the runs holds a Third Mates License and has had two years of intensive familiarity with MSI's training courses, simulator operation, and scenario design. In fact, the Observer was largely responsible for designing and programming the events comprising each of the scenarios used in this study. It should also be noted that the number of errors committed during the runs is probably inflated because of the artificially high workload demand placed on the mariners. It should be kept in mind that each mariner was alone on the bridge (except for a helmsman) under conditions in which they would normally have at least one other officer present, and was responsible for all aspects of bridge management and functions.

Table D-2 below presents a tally of the types of errors that were made by the mariners. The number of mariners represented in the tallies for each scenario is given at the top of the table. The table also gives the weighting factor assigned to each error by expert mariners during the development of this measure before the experiment began. As might be expected, more navigation errors occurred overall in the ECDIS without Automatic Positioning scenarios (Scenarios 3 and 6), although the nature of the most predominant

Table D-2. Tally of errors committed during each scenario for all mariners.

		SCENARIO									
		1	2	3	4	5	6	7	8	9	total # of errors
		n= (3)	(5)	(3)	(6)	(6)	(6)	(6)	(6)	(5)	
NAVIGATION ERRORS:	wt										
Unnecessarily close to shallow water	(2)									1	1
Missing channel entrance	(2)		1								1
Leaving the channel	(2)			1				1			2
Believing that the ship is somewhere it isn't, (difficult to determine this)	(1)		1		1	1	6	1	1	1	12
Striking a buoy	3)			2			1				3
Operating on the wrong side of the channel, when unnecessary, for each three minutes	(1)	6		5			2			1	14
Dropping anchor in the wrong anchorage	(1)								1	3	4
Improper use of radar for navigating	(1)	1					1				2
total # of errors		7	2	8	1	1	10	2	2	6	39
COLLISION AVOIDANCE ERRORS:											
Dangerously close to a collision	(4)	1			2		1			1	5
Unnecessarily Close to traffic	(2)	2	2	1	2		2	1	1	2	13
Failing to communicate to important traffic	(2)	4	8	2	6	5	2	10	9	5	51
Failing to sound fog signal	(1)				2			3			5
Failing to comply with the rules of the road	(3)		1		2	1					4
Poor choice of maneuver, where the rules of the road are not broken	(2)			1		1		2			4
Operating at an excessive speed	(2)	2	1						1		4
Using radar on improper scale, or other poor monitoring condition	(1)				5	2		4	1		12
Failing to detect a target	(2)				3		2				5
Late detection of a target	(1)		1		3						4
Not monitoring proper channels	(1)								1		1
total # of errors		9	13	4	25	9	7	20	13	8	108
BRIDGE MANAGEMENT ERRORS:											
Missing a few Log Book entries, less than 40%	(1)	3	3	4	4	10	6	5	7	3	45
Missing many log book entries, 40% or greater	(2)	2	5	1	2	2	4	2	2	3	23
Failing to test the steering gear	(4)		1								1
Failing to test the EOT	(2)								1	1	2
Failing to Call Engine Room prior to Arrival, and at Arrival	(1)				1	1					2
Failing to set radios to proper channels	(2)				2			1			3
Failing to notify important personnel	(1)								1	1	2
Failing to prepare anchor before entering restricted waterway	(3)								1	1	2
Failing to check in with VTS at designated times and places	(1)		1	1	1	2	4	2	2	2	15
total # of errors		5	10	6	10	15	14	10	14	11	95

error was different. The other type of error which occurred relatively frequently was operating on the wrong side of the channel when unnecessary. As the table shows, this error occurred mostly in Scenarios 1 and 3, and while it might be understandable for Scenario 3, it is not clear why this should have happened in Scenario 1, when automatic updating of position was available.

The most common type of collision avoidance error by far was the failure to communicate with important traffic. While this probably has little to do with the presence or absence of ECDIS, it does warrant further investigation for general safety concerns.

For analysis, the errors were tabulated and weighted based on the nature of the error, with a larger penalty given to errors impacting on vessel safety. Each mariner received an overall scenario score as well as scores for errors in navigation, collision avoidance and bridge management events. The only significant correlation obtained was between the mariner's reported navigation workload (discussed below) and the navigation error score (Correl. =. 33, $p < 0.05$), indicating that navigation errors increased as navigation workload increased.

D.4 MEASURES OF FEATURE AND FUNCTION USE

D.4.1 Observer's Tally

Data collected for ECDIS feature/function use was used to determine what features are actually used under various circumstances. Templates that were replicas of the control panels of each ECDIS unit were constructed and are presented in Figures D-8 and D-9. During the experimental runs, one experimenter was located at the Human Factors Station and monitored the ECDIS, via a camera trained on the control panel, and kept a tally of all the functions used. A tick mark were placed next to the appropriate feature, including changes in chart scales and alarm warnings, and a running total was kept. These were analyzed to determine the importance and effectiveness of each feature/function.

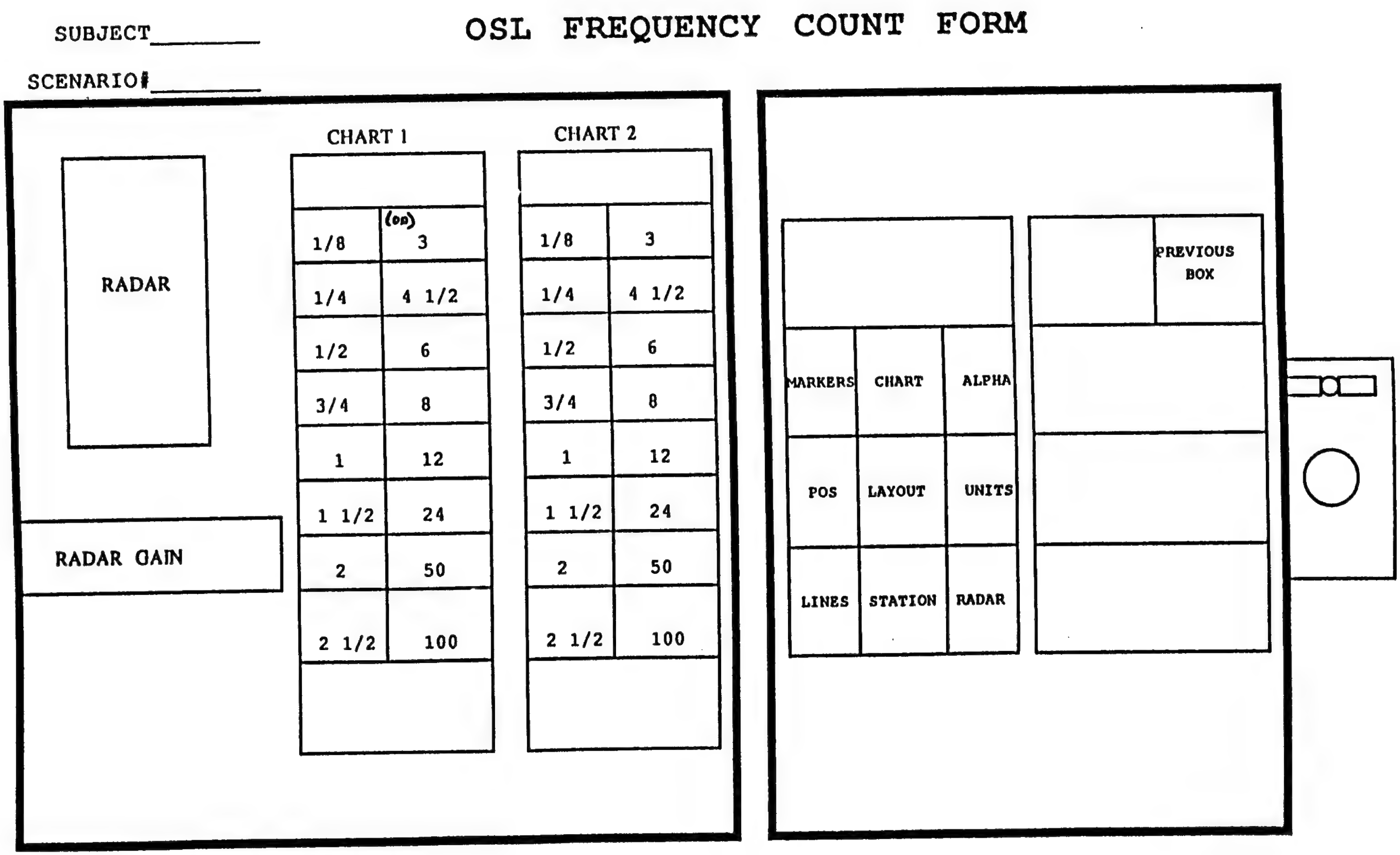


Figure D-8. Template of OSL Control Panel Used to Tally Feature Use

MARKERS

(on) Compass Rose
(on) North Arrow
Bearing Line

CHARTS

n12327	no chart
n12326	n12334

POSITION-Adjust Offset

Move Trackball to Adjust
Set Offset to 0

LAYOUTS

Docking	Local Nav
(on) Extended Nav	Split Screen

RADAR

Drop Target
Test Pattern
Trigger Calibrate
Azimuth Calibrate
Gyro Delay

Figure D-8. Template of OSL Control Panel Used to Tally Feature Use (cont.)

ROBERTSON FEATURE/FUNCTION TALLY SHEET

MARINER # ________

SCENARIO # ____________

NO CURSOR	NAV-LINES	ARPA TARGETS
MANUAL CENTER	RANGE/BEARING	DR-RESET

BEACON (on)	BUOY (on)
MARK (on)	DEPTH
TEXT (on)	GRID (on)

ALARM	RESET
MONITOR	PLAN

CHART	SHIP	ANTS	ARPA
NEW SCALE (write in level/scale chosen) strt:	VECTOR ON/OFF (on)	ENABLE ANTS (on)	ENABLE TARGETS ____
	VECTOR TIME (on: 6 min)	ETA	vectors on/off ________
	TRACK TIME ON/OFF (off)	POS	true/relative ________
	LABELS ON/OFF (off)		
	MANUAL INPUT	CTS	
TRUE MOTION (on)	input SPEED ________	XTE	
	input COURSE ________		
RELATIVE MOTION	input DRIFT ________	WOW	
	input SET ________		
AUTO CENTER	RESET DR-POS ________		

ON = 1
OFF = 2

Notes:

Figure D-9. Template of Robertson Control Panel Used to Tally Feature Use

D.4.2 Log of Paper Chart Use

As previously mentioned, all mariners were provided with charts covering the area to be transited. These were kept on the bridge chart table, but folded so their use would be conspicuous to observers at the Human Factors Station. During the ECDIS-assisted transits, mariners were provided with a log sheet for paper chart use, in which they were instructed to keep track of when they referred to the chart. Included in the log was information pertaining to the time they referred to the chart, chart number, the information obtained and reason for chart use. These data were collected and analyzed to identify any problems encountered with ECDIS and what additional information was required, and are presented in Appendix E.

D.4.3 Post-Scenario Questionnaires

Detailed post-scenario questionnaires were developed to elicit information from the mariners regarding a range of issues relating to their most recently completed transit. Each questionnaire was scenario specific, and included mariner self-ratings of performance, their difficulty in using and confidence in the ECDIS, what navigational and charted features they actually used, and what they wanted to use. In addition, there were open-ended questions regarding the relative safety of manually updating Ownship's position on the ECDIS, the safety and usefulness of the radar overlay and ARPA targets, and whether ECDIS supported all the navigational functions they wanted to perform. Figure D-10 presents a composite of the questions for each scenario, along with response data where appropriate.

D.4.4 Post-experiment Questionnaire

Following the completion of all nine simulator runs, the mariner's filled out a post-experiment questionnaire, which was detailed and global in scope, asking the mariners for their expert opinions and views on a wide range of navigational issues and challenges. In addition, this time was used by the experimenters to re-visit any of the test scenarios with the mariners to insure that they had proceeded as planned and that no simulator-related problems had interfered with their performances. Issues covered included the training

program, bridge configuration, ECDIS features most and least important, the ECDIS display, radar features, safety and workload, and use of ECDIS in the 'real world". A sample of this questionnaire is provided as Figure D-11. Note that responses to some of the questions are discussed throughout the main report.

MARINER#_________ RUN# _____

COMPOSITE OF POST-SCENARIO QUESTIONNAIRES AND RESPONSES

Instructions: PLEASE ANSWER THE FOLLOWING QUESTIONS REGARDING YOUR LAST TRANSIT.

Questions common to all scenarios:

1. Rate your overall navigational performance during your last transit.

1 2 3 4 5
poor excellent

	Sc 1	Sc 2	Sc 3	Sc 4	Sc 5	Sc 6	Sc 7	Sc 8	Sc 9
ave	3.33	4.20	2.67	4.08	3.92	3.42	3.75	3.50	4.00
sd	0.58	0.45	0.58	0.20	0.49	1.28	0.61	0.84	0.00
(n)	(3)	(5)	(3)	(6)	(6)	(6)	(6)	(6)	(4)

2. Rate your overall safety/collision avoidance performance during your last transit.

1 2 3 4 5
poor excellent

	Sc 1	Sc 2	Sc 3	Sc 4	Sc 5	Sc 6	Sc 7	Sc 8	Sc 9
ave	2.67	3.40	3.67	3.50	3.67	3.58	3.67	3.83	3.00
sd	1.15	0.55	0.58	0.55	0.82	0.92	0.52	0.41	0.82
(n)	(3)	(5)	(3)	(6)	(6)	(6)	(6)	(6)	(4)

3. Rate your overall management of the bridge during your last transit.

1 2 3 4 5
poor excellent

	Sc 1	Sc 2	Sc 3	Sc 4	Sc 5	Sc 6	Sc 7	Sc 8	Sc 9
ave	2.33	2.60	2.50	3.67	2.67	3.25	3.33	3.08	2.75
sd	0.58	1.14	1.32	0.52	0.52	0.76	0.52	0.66	0.50
(n)	(3)	(5)	(3)	(6)	(6)	(6)	(6)	(6)	(4)

4. Using the choices given below, indicate your primary and secondary method of navigation during each portion of the transit. (data discussed in Section 5)

Choices:

1. **Plotting on paper chart**
2. **Conning using radar/ARPA**
3. **Conning using visual means**
4. **Conning using ECDIS** (choice not available for Sc # 8 and 9)
5. **Other (please specify)**

TRANSIT SEGMENTS **(Scenario 1)**	PRIMARY METHOD	SECONDARY METHOD (if any)
Start to Ambrose Light		
Ambrose Light to Sea buoy		
Sea buoy to Ambrose Channel		
Ambrose Ch to Verraz. Narrows Br		
Verrazano Narrows Br to Anch		

Figure D-10. Annotated Composite Post-Scenario Questionnaire

TRANSIT SEGMENTS (Scenario 2)	TRANSIT SEGMENTS (Scenario 3)
Start to BA buoy	Anchorage to Verrazano Narrows Bridge
BA buoy to Ambrose Light	Verraz. Narrows Br to Ambrose Channel
Ambrose Light to Sea buoy	Ambrose Channel to Sea buoy
Sea buoy to Ambrose Channel	Sea buoy to Ambrose Light
Ambrose Ch to Verrazano Narrows Br	Ambrose Light to End
Verraz. Narrows Br to Anchorage	

TRANSIT SEGMENTS (Scenario 4)	TRANSIT SEGMENTS (Scenario 5)
Start to Ambrose Light	Start to SF buoy
Ambrose Light to Sea buoy	SF buoy to SF Channel
	SF Channel to Golden Gate Bridge
	Golden Gate Bridge to Alcatraz
	Alcatraz to Oakland Bay Bridge
	Oakland Bay Bridge to Anchorage

TRANSIT SEGMENTS (Scenario 6)	TRANSIT SEGMENTS (Scenario 7)
Start to SF buoy	Anchorage to Oakland Bay Bridge
SF buoy to SF Channel	Oakland Bay Bridge to Alcatraz
SF Channel to Golden Gate Bridge	Alcatraz to Golden Gate Bridge
	Golden Gate Bridge to SF Channel
	SF Channel to SF buoy
	SF buoy to End

TRANSIT SEGMENTS (Scenario 8)	TRANSIT SEGMENTS (Scenario 9)
Start to NA buoy	Start to SF buoy
NA buoy to Ambrose Light	SF buoy to SF Channel
Ambrose Light to Sea buoy	SF Channel to Golden Gate Bridge
Sea buoy to Ambrose Channel	Golden Gate Bridge to Alcatraz
Ambrose Ch to Verraz. Narrows Br	Alcatraz to Oakland Bay Bridge
Verrazano Narrows Br to Anch	Oakland Bay Bridge to Anchorage

Questions specific to ECDIS scenarios: Sc # 1, 2, 3, 4, 5, 6, and 7

1. How confident were you in using ECDIS as your primary method of navigation?

1 2 3 4 5

not confident very confident

	Sc 1	Sc 2	Sc 3	Sc 4	Sc 5	Sc 6	Sc 7
ave	4.83	4.80	1.33	4.50	4.00	1.17	3.50
sd	0.29	0.45	0.58	0.84	1.10	0.41	1.64
(n)	(3)	(5)	(3)	(6)	(6)	(6)	(6)

What circumstances lead you to switch to another method (if you did)?

Given the option, would you have preferred to navigate your last transit using the ECDIS or a paper chart? Please explain.

Figure D-10. Annotated Composite Post-Scenario Questionnaire (cont.)

2. Rate the overall difficulty of operating the ECDIS.

1 2 3 4 5
difficult easy

	Sc 1	Sc 2	Sc 3	Sc 4	Sc 5	Sc 6	Sc 7
ave	3.67	3.40	2.83	4.00	3.58	2.00	3.83
sd	1.53	1.14	1.89	0.89	0.49	0.00	0.75
(n)	(3)	(5)	(3)	(6)	(6)	(6)	(6)

If you experienced any problems operating the ECDIS, what were they?

3. What charted features would you *have liked to have used* but were not available on the ECDIS? Did you refer to the paper chart for the information? (see Section 6 and Appendix E)

4. Did the ECDIS support you in all of the navigational functions (e.g., calculating ETA, taking ranges/bearings, etc.) you wanted to perform? If no, what functions were you unable to perform and why? (see Section 6 and Appendix E)

5. Can you think of any other aspects of ECDIS or ECDIS-based navigation that may potentially lead to an ambiguous or dangerous situation in the real world?

Questions specific to OSL scenarios: Sc # 1 (n=3), 2 (n=5), and 3 (n=3)

1. Check the navigational(text box)data you *actually used* during your last transit:

total count		total count	
(1)	1. Vessel Lat/Long	(8)	6. X-DS - Cross Track Distance
(7)	2. Gyro	(10)	7. CTS - Course to Steer
(0)	3. Cursor Lat/Long	(6)	8. Radar Overlay
(11)	4. Cursor Range and Bearing	( )	9. OTHER (please list)
(4)	5. Target Range and Bearing		

What navigational data would you have *liked to have used* but were not available on the ECDIS? Did you get the data from another source? (data presented in Section 6)

2. Would you have used a head up display if it were available on the ECDIS? Why or why not? (Sc # 3 only) (Total of 3 responses, all preferred North Up)
How important is it to have the option of both north up and head up displays available on the ECDIS?

1 2 3 4 5
not important very important

ave 2.00
sd 1.73
(n=3)

3. How useful was having depth contours displayed on the ECDIS?

1 2 3 4 5
not useful very useful

	Sc 1	Sc 2	Sc 3
ave	3.00	2.40	1.50
sd	1.00	0.55	0.71
(n)	(3)	(5)	(2)

Figure D-10. Annotated Composite Post-Scenario Questionnaire (cont.)

Questions specific to Robertson scenarios: Sc # 4 (n=6), 5 (n=6), 6 (n=6), and 7 (n=6)

1. Check the navigational(text box)data you *actually used* during your last transit:

total count		total count	
(18)	1. Crs - Course (Gyro Course)	(10)	7. ARPA data
(17)	2. Spd - Speed	(20)	8. Range/Bearing
(10)	3. Cmg - Course Made Good	(16)	9. Distance to next waypoint
(11)	4. Smg - Speed Made Good	(18)	10. ETA to next waypoint
(6)	5. Set - Drift Course	(16)	11. Ship speed/heading vector
(5)	6. Drift - Drift Speed	(12)	12. Track time/history
		( )	13. OTHER (please list)

What navigational data would you have *liked to have used* but were not available on the ECDIS? Did you get the data from another source? (see Section 6 and Appendix E)

2. Check the charted features you *actually used* during your last transit:

total count		total count	
(16)	1. Beacons	(15)	5. Depth markings (soundings, contour lines)
(21)	2. Buoys	(8)	6. Geographic names
(9)	3. Dangers	(8)	7. Lat/Long Grid
(23)	4. Traffic Lanes	(7)	8. Nav Aid Characteristics
		( )	9. OTHER (please specify)

Questions specific to manual update scenarios: Sc 3 (n=3) and 6 (n=6)

1. Were you able to manually fix your position on the ECDIS to your satisfaction? If not, what problems did you encounter? (see Section 5.4.4)

2. When manually fixing your position on the ECDIS, was it easier or more difficult as compared to traditional methods using the paper chart:

Using radar overlay: (Sc # 3 only)

1	2	3	4	5		
more difficult		same		much easier	ave	2.0
					sd	1.0

Using ranges/bearings and/or lat and long: (Sc # 3 and 6)

1	2	3	4	5		
more difficult		same		much easier	ave	2.67
					sd	1.37

What in particular made it easier or more difficult?

3. Rate the level of navigational safety during the portion of the transit in which you were manually fixing your position on the ECDIS, as compared to traditional methods using the paper chart.

1	2	3	4	5		OSL	Robertson
					ave	2.00	2.17
less safe		same		safer	sd	1.00	0.75

What in particular do you think made manually fixing your position on the ECDIS less or more safe?

Figure D-10. Annotated Composite Post-Scenario Questionnaire (cont.)

Questions specific to radar -- Sc # 1 and 3, and ARPA target -- Sc # 4 overlay scenarios

1. Please rate the usefulness of a full radar overlay (Sc # 1 and 3; rate the usefulness of overlaying selected ARPA targets ... Sc # 4) for performing the following functions. (Assume that the radar overlay display is as good as a stand alone display.)

   As a check on accuracy of primary positioning system:
   1 2 3 4 5
   not useful — very useful

   As the primary method for positioning vessel/chart:
   1 2 3 4 5
   not useful — very useful

   For collision avoidance/ARPA tasks:
   1 2 3 4 5
   not useful — very useful

2. Please rate the safety of using a full radar overlay (Sc # 1 and 3; rate the usefulness of overlaying selected ARPA targets ... Sc # 4) when performing the following functions. (Assume that the radar overlay display is as good as a stand alone display)

   As a check on accuracy of primary positioning system:
   1 2 3 4 5
   unsafe practice — safe practice

   As the primary method for positioning vessel/chart:
   1 2 3 4 5
   unsafe practice — safe practice

   For collision avoidance/ARPA tasks:
   1 2 3 4 5
   unsafe practice — safe practice

3 Do you have any safety or other concerns/observations regarding the full radar overlay (Sc # 1 and 3; regarding overlaying selected ARPA targets ... Sc # 4)? If yes, please explain. (Data discussed in Section 7)

Figure D-10. Annotated Composite Post-Scenario Questionnaire (cont.)

MARINER # _______

ECDIS PHASE II
POST-EXPERIMENT DEBRIEFING FORM

THE TEST PROGRAM AND ITS EFFECTS ON PERFORMANCE

1. Rate the adequacy of the training you received in using the ECDIS devices:

   OSL ECDIS:
   1 poor   2   3   4   5 excellent

   ROBERTSON ECDIS:
   1 poor   2   3   4   5 excellent

   Comment on the strengths and weaknesses of that training for the excercises that followed.

   Describe any aspects of either ECDIS on which you would like to have been better trained/informed before navigating the M/V ECDIS.

   How many "watches" did you complete before you felt comfortable navigating with the:

   OSL ECDIS:
   ( ) 1   ( ) 2   ( ) more than 2   ( ) never

   ROBERTSON ECDIS:
   ( ) 1   ( ) 2   ( ) more than 2   ( ) never

   What did you learn from using the devices that you did not learn from the training?

2. Rate the overall realism of the simulated watches you participated in:

   1 poor   2   3   4   5 excellent

   Explain what you felt was unrealistic.

3. Were there any aspects of the simulator or simulations that may have caused you to perform in a manner significantly different from how you would perform in the real world?
   ( ) Yes   ( ) No   If Yes, please explain:

4. Did the layout of the bridge influence the performance, safety, and workload during the runs?

   How would you like to have seen the bridge arranged? (Draw a picture on the back of this page if you wish.)

5. Was the workload appropriate for one watchstander? Where there differences among conditions in the appropriateness of workload? How would you have preferred to see the workload distributed?

6. Under what additional circumstances, conditions, or geographical areas would you have liked to have the opportunity to evaluate ECDIS? Why?

The following questions ask for your professional opinion and assessment of a wide range of ECDIS-related issues. Please try to visualize this technology on board your vessel in your present trade. Assume that the technology has matured and technical problems relating to system reliability, system bugs and the like have been resolved. Also answer the questions only in relation to the **navigation monitoring task**. Route planning will be considered on another questionnaire.

Figure D-11. Post-Experiment Questionnaire

MARINER # _______ <u>ENC</u>

7. For safe and efficient ECDIS-based position monitoring, indicate which **charted features** you think should **ALWAYS** be displayed as appropriate to the chart scale, which should be displayed at the **USERS OPTION** (i.e., the user can turn on/off with keystroke), and which **NEED NOT** be displayed at all on the electronic chart. Use the space provided for comments, and list any additional charted features at the bottom.

KEY: A- ALWAYS DISPLAY **U-** USER "ON/OFF" OPTION **N-** NEED NOT DISPLAY

CHARTED FEATURES	(A-U-N)	COMMENTS
LANDMASS RELATED		
coastline/landmass		
coastal topography		
land feature/characteristics features		
names-landmasses, islands, points etc.		
NAVIGATION AID RELATED		
indication of fixed aids to navigation		
indication of floating aids to navigation		
light / sound characteristics		
physical classification (can/nun)		
physical description (e.g. white tower)		
visual and radar conspicuous features		
radio characteristics (RACON)		
AREA DESIGNATIONS		
Federal channel lines		
navigation lanes/fairways.		
prohibited and restricted areas		
anchorages		
pilot areas		
SEABED/BOTTOM FEATURES		
spot soundings		
bottom contours		
bottom characteristics		
cable/pipeline areas		
OTHER INFORMATION		
indication of isolated dangers (wrecks, rocks, overhead bridges, etc.)		
details of isolated dangers		
indication of cautionary notes		
details of cautionary notes		
Lat/Long grid lines		
compass rose		
magnetic variation		
geodetic datum		
indication of units of depths and heights		
ENC edition date		

Star the <u>three</u> charted features that you feel are *most* important to the safety of ECDIS use. When and why did you use each (or would you have liked to use if available). Please comment.

Cross out the <u>three</u> charted features that you feel are *least* important to the safety of ECDIS use.

Figure D-11. Post-Experiment Questionnaire (cont.)

MARINER # _______

ENC

8. Should the user be able to turn on and shut off various layers of attributes (e.g., the buoys, text, beacons)? Please describe any situations which might apply to your answer.

Is chart-based text (e. g., landmass names names, navigation aid characteristics, course) useful and/or necessary on the electronic chart? Would you prefer to point to an item with the cursor, for example, and get information on a separate text display?

Monitoring

9. What capabilities should the ECDIS have to allow the operator to conduct the sames navigational routines and plotting as done on paper chart with a ruler?

( ) triangles, dividers, pencil, etc
( ) variable range marker
( ) fixed range marker
( ) electronic bearing line (fixed and free) with built in VRM
( ) navlines
( ) any others? (please list)

Figure D-11. Post-Experiment Questionnaire (cont.)

10. Indicate which **ECDIS-generated features and functions** you think should **ALWAYS** be displayed as appropriate to the chart scale, which should be displayed at the **USERS OPTION** (i.e., the user can turn on/off with keystroke), and which **NEED NOT** be displayed at all. Use the space provided for comments, and list any additional ECDIS-generated features and functions at the bottom.

KEY: A - ALWAYS DISPLAY   U- USER "ON/OFF" OPTION   N - NEED NOT DISPLAY

FEATURES & FUNCTIONS	(A-U-N)	COMMENTS
OWNSHIP INFORMATION		
ownship outline		
Past track		
vector of ownship heading and speed		
vector of course and speed made good		
NAVIGATION TOOLS AND DATA		
display planned trackline		
course to steer (trackline)		
display waypoint and waypoint number		
display wheel over points/turn radius		
display range rings		
provide method for manual fix taking		
display fix marker and time		
display dead reckoned position and time		
CALCULATED/SPECIAL		
display ownship's safety depth contour		
display current vectors		
display visual limits of lights		
display selected ARPA targets		
display overlay of actual radar		
display chart north up and course up		
Set and Drift		
ETA to waypoint		
zoom in/ out function		
navigation fault alarm (e.g. GPS down)		
off track alarm		
grounding alarm		
OTHER INFORMATION		
scale bar		
chart scale boundaries		

Star the three ECDIS-generated features and functions that you feel are *most* important to the safety of ECDIS use. When and why did you use each (or would you have liked to use if available). Please comment.

Cross out the three ECDIS-generated features and functions that you feel are *least* important to the safety of ECDIS use.

Figure D-11. Post-Experiment Questionnaire (cont.)

11. How important is it to have the option of both true and relative chart motions available?

1 2 3 4 5
not important very important

What advantages or problems do you see in having both available? (Please consider both experienced and more junior officers.)

12. How important is it to have the option of both north up and head up displays available?

1 2 3 4 5
not important very important

What advantages or problems do you see in having both available? (Please consider both experienced and more junior officers.)

13. How important is it to be able to offset ownship from the center of the screen as did the Robertson device? Is the offset important if you have more than one window as did the OSL?

14. How many displays do you feel are necessary to fulfill the independent ECDIS functions of route planning, navigation monitoring, and display of auxiliary information? Is it sufficient to switch back and forth as on the Robertson ECDIS, or would you prefer that the navigation monitoring display is always visible as on the OSL?

Radar

15. Do you think radar/ARPA features should be integrated into the ECDIS? What are the advantages and disadvantages of such integration? What would be the effects on safety and on workload?

Should that integration be as a complete overlay, like the OSL or as ARPA targets alone, like the Robertson? What are the advantages or disadvantages of each possibility? What would be the effects on safety and workload of each possibility?

Could such an integrated device ever replace one of the radars on the bridge?

General

16. What do you feel are the best and worst aspects of ECDIS as presented by the two devices you saw?

What improvements would you suggest?

Safe nav

17. Do you think that ECDIS can replace the paper chart in all operational circumstances? What could be added or improved in order to make this possible? Are there any aspects of ECDIS technology that make it an unacceptable replacement for the paper chart?

Figure D-11. Post-Experiment Questionnaire (cont.)

MARINER # _______

USE OF ECDIS IN THE REAL WORLD

18. How would you expect an ECDIS to be used on the last ship on which you sailed? Where would it be placed on the bridge? How would it be incorporated into watchstanding practices? Would you expect it to be accepted?

19. Would you trust ECDIS devices in the real world? Would you have confidence in watchstanding using such devices? What factors would limit your confidence? Are they primarily device characteristics, positioning accuracy, training, or others?

20. Do you see a place for ECDIS in piloting? How would you expect the wide-spread availability of these devices to affect piloting practice and regulation?

21. Does an integrated navigation display -- chart and radar -- have a function in reduced visibility beyond that played by radar alone? How would you expect the wide-spread availablity of these devices to affect practice and regulation?

22. Does the present training and certification for watchstanding using paper charts and radar prepare for ECDIS use? If not, what kinds of training, certification, etc. do you think would be necessary for the effective use of these devices? In the long run do you see ECDIS as increasing or decreasing the general level of skill needed by a watchstander?

23. What pitfalls or dangers in using ECDIS might a more junior officer experience?

24. Was the workload appropriate for one watchstander? How would you have preferred to see the workload distributed? What factors would affect the workload and its distribution? Do you see the need or possibility of changing staffing standards with the availability of the ECDIS technology?

25. Does the use of the ECDIS devices have any relation to fatigue? Would it increase or decrease the fatigue caused by standing a watch? For a fatigued watchstander, would it make his job easier or harder?

26. Design your dream ECDIS. First consider the ECDIS as it would be used during route monitoring. Then consider passage planning. Mention which aspects of either (or neither) ECDIS you worked with that you would include, modify, or eliminate. Try to consider as many circumstances and conditions as you can to design an ECDIS that will contribute to safer navigation and lower navigational workload for the user. Use the back of this sheet if necessary. Happy dreams!!

THANK YOU FOR PARTICIPATING!!

Figure D-11. Post-Experiment Questionnaire (cont.)

APPENDIX E.0 SUPPLEMENTARY MATERIAL FOR SECTIONS 5.0, 6.0, AND 7.0 RESULTS AND DISCUSSION

E.1 DISCUSSION OF STATISTICAL ANALYSES

Many of the performance scores discussed below and throughout the Main report were subjected to statistical analyses. In particular, the Repeated Measures Analysis of Variance (ANOVA) procedure was used, and Single Degree of Freedom Contrasts were performed. It is the F values and significance levels of these contrasts that are cited in the text of the Main Report.

Note in these figures that in addition to the usual p-value, p-values for which the degrees of freedom are adjusted using both the Greenhouse-Geisser (G-G) and Huynh-Feldt (H-F) epsilon factors are also provided. These epsilon factors take into account any violations in the assumptions about the correlation between the observations. The G-G tends to be conservative, while the H-F tends to be somewhat liberal. A discussion of these factors can be found in Maxwell and Delaney (1990) as well as the operations manual for Abacus Concepts SuperAnova (1989). As a general rule, the most conservative of the three p-values is reported in the text.

Due to occasional malfunctions of the prototype ECDIS devices or to other problems, some runs were lost. While the means and standard deviations reported in the text reflect only data actually collected, estimated values were used for the both ANOVA and supporting contrasts.

E.2 PRELIMINARY ANALYSIS OF THE NASA TASK LOAD INDEX

The NASA-TLX subjective rating scales were used to evaluate the mariner's experience of workload. Appendix D contains sample materials and the Main Report presents the more striking findings. This section presents some of the more preliminary findings as well as supporting tables of statistical data.

As a preliminary examination of the effects, the mean (and standard deviation) workload scores for each scenario are shown in Table E-1 below.

Table E-1. Mean Workload Reported for Each Scenario on a Zero- to -100 Workload Scale

Source of Workload		Scenario 1	2	3	4	5	6	7	8	9
Navigation	mean	33.84	39.00	73.42	24.42	38.33	63.82	40.69	49.86	58.17
	sd	12.61	16.72	13.20	6.12	13.03	17.95	9.79	13.53	7.08
	n	3	5	3	6	6	6	6	6	4
Collision Avoidance	mean	63.94	64.25	60.03	57.36	48.87	51.31	55.80	52.78	63.08
	sd	20.43	12.21	16.14	17.35	15.51	10.45	14.60	18.37	18.04
	n	3	5	3	6	6	6	6	6	4
Bridge Management	mean	54.60	58.76	67.54	46.24	57.53	50.56	46.75	54.81	54.77
	sd	7.12	18.06	24.59	15.24	15.27	16.78	9.36	12.04	9.90
	n	3	5	3	6	6	6	6	6	4

An underlying assumption made when analyzing these data is that navigation workload (as opposed to collision avoidance or bridge management) would be most dramatically influenced by introducing ECDIS to the bridge. Therefore, although some analyses were performed for the collision avoidance and bridge management data, most of the effort was focused on navigation workload, including statistical comparisons between ECDIS scenarios and between ECDIS versus baseline scenarios. As Table E-1 shows, the assumption is supported in that both collision avoidance and bridge management workloads were fairly consistent across the scenarios, while navigation workload was much more variable. This table shows that the NASA-TLX workload measurement technique was indeed sensitive to variations in navigation workload represented by the different bridge conditions presented to the mariners.

Another assumption made when comparing the scenarios on any of the measures, was that the overall distribution of workload was similar across the scenarios (via the mix of navigation, collision avoidance and bridge management tasks). To verify this assumption, the overall workload scores for each of the three bridge tasks was weighted by the proportion of time the mariner reported spending on each task . A single score was computed for each scenario, which reflected a combination of workload for all three tasks and the percent of time spent on each. The mean overall workload for each scenario is in shown in Figure E-1 below. No analyses were done on these data.

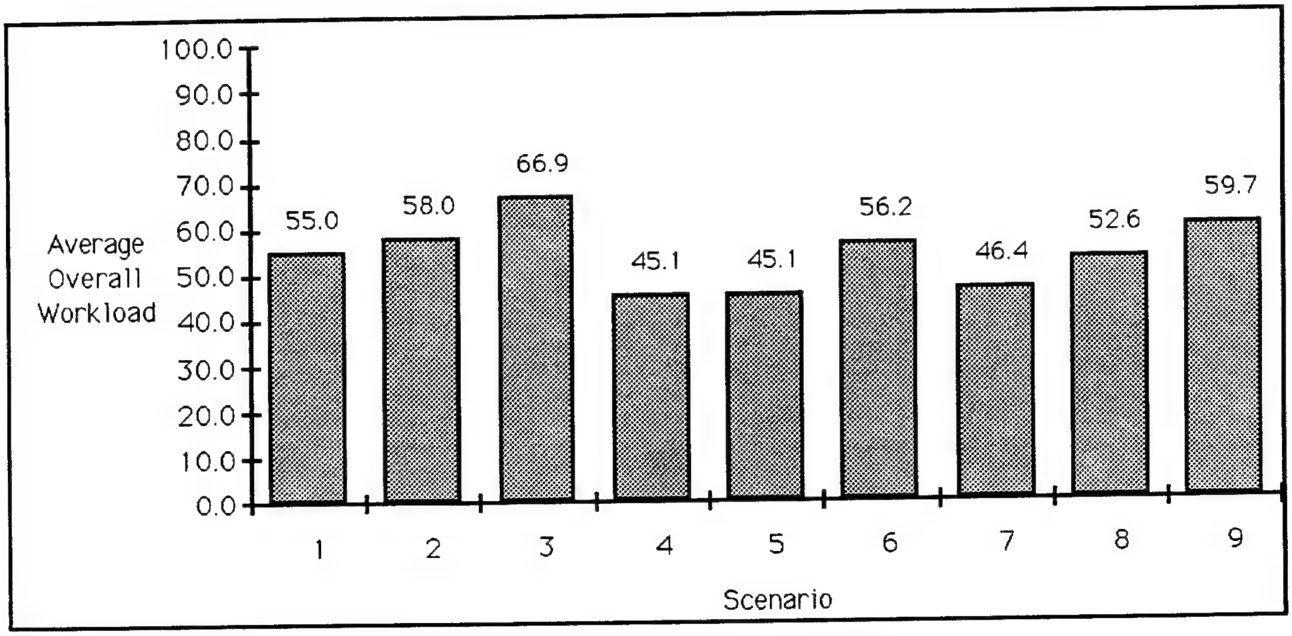


Figure E-1. Mean Overall Workload by Experimental Scenario

E.3 SCENARIO ANALYSES OF ECDIS EFFECTS ON WORKLOAD

The effect of ECDIS on mariner workload was described in Section 5 of the Main Report. The effect was further analyzed for the individual scenarios. Since navigation-related activities were the most clearly affected by the presence or absence of ECDIS, and since several of the mariners indicated that they consider navigation to be a very separate thought process from collision avoidance, the following discussion is concentrated on the findings for navigation workload. While there were some statistically significant differences obtained in mean collision avoidance workload among scenarios, the presence or absence of ECDIS did not produce a consistent effect. The mean level of workload for bridge management-related tasks does not appear to be affected by the introduction of the ECDIS to the bridge.

The mean navigation workload for the conventional bridge (Scenario 8) as compared to OSL with automatic positioning (Scenario 2) is shown in Figure E-2. The reduction in mean navigation workload between these scenarios is attributable only to the availability of ECDIS because the routes into New York Harbor were identical and both transits were

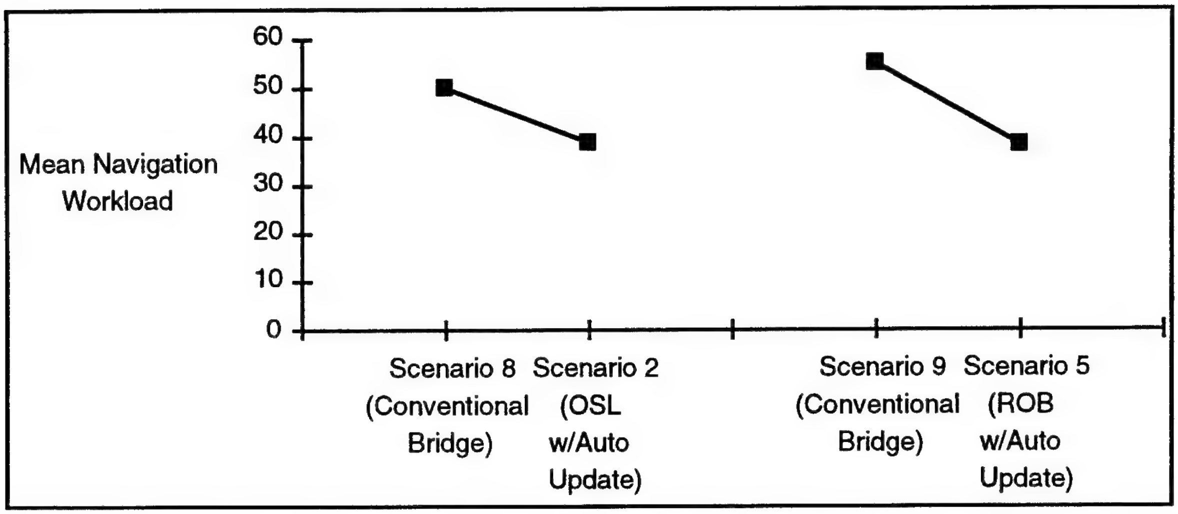


Figure E-2. Mean navigation workload during conventional bridge scenarios (8 and 9) each versus a comparable ECDIS scenario (2 and 5)

made in clear visibility. The difference in mean navigation workload between these two scenarios was statistically significant ($F = 3.96$, $p < 0.07$). A second, similar comparison is also presented in Figure E-2. In this case, navigation workload on a conventional bridge (Scenario 9) is compared with the Robertson ECDIS (Scenario 5), with both transits going from the coastal zone into San Francisco Harbor in clear visibility. Again, there is a relatively large reduction in navigation workload that is statistically significant ($F = 8.84$, $p < 0.03$), further supporting the hypothesis that ECDIS does reduce perceived navigational workload.

The supporting ANOVA table and contrasts for the workload scores discussed above and in the Main Report are presented in Figure E-3. Figure E-4 presents similar tables and contrasts for the analysis of percent of time spent on navigation, collision avoidance and bridge management tasks discussed in the Main Report. The analyses performed on the primary method of navigation data are given in Figure E-5, and Figure E-6 presents the ANOVA table for average situational awareness. Various correlations between these measures can be found in Table E-2. The charted features and navigational data mentioned on the paper chart use forms and in the questionnaires are compiled and presented in Table E-3. Finally, a summary of the average cross-track distance data and the t-values for certain comparisons are presented in Table E-4, followed by a complete set of the composite trackplots in Figures E-7 through E-15.

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	G-G	H-F
Subject	5	5429.312	1085.862				
Bridge Task	2	2559.747	1279.874	1.934	.1949	.1989	.1949
Bridge Task * Subject	10	6616.970	661.697				
Scenario	8	4457.336	557.167	4.240	.0009	.0145	.0009
Scenario * Subject	40	5256.721	131.418				
Bridge Task * Scenario	16	6570.921	410.683	4.467	.0001	.0163	.0002
Bridge Task * Scenario * Subj...	80	7354.348	91.929				

Dependent: Workload Scores

Table of Epsilon Factors for df Adjustment
Dependent: Workload Scores

	G-G Epsilon	H-F Epsilon
Bridge Task	.933	1.467
Scenario	.464	1.972
Bridge Task * Scenario	.204	.633

NOTE: Probabilities are not corrected for values of epsilon greater than 1.

SINGLE DEGREE OF FREEDOM CONTRASTS

Effect: Bridge Task * Scenario
Dependent: Navigation Workload Scores

ROB ECDIS vs. Conventional Bridge

	Cell Weight
NAV, Sc5	1.000
NAV, Sc9	-1.000

df	1
Sum of Squares	813.124
Mean Square	813.124
F-Value	8.845
P-Value	.0039
G-G	.0338
H-F	.0111

OSL ECDIS w/ Auto Positioning vs OSL Manual Positioning

	Cell Weight
NAV, Sc1	1.000
NAV, Sc3	-1.000

df	1
Sum of Squares	1902.903
Mean Square	1902.903
F-Value	20.700
P-Value	.0001
G-G	.0079
H-F	.0003

Figure E-3. Analysis of Variance (ANOVA) Tables and Single Degree of Freedom Contrasts for Workload Scores

SINGLE DEGREE OF FREEDOM CONTRASTS (cont)

Effect: Bridge Task * Scenario
Dependent: Navigation Workload Scores

OSL ECDIS vs Conventional Bridge

	Cell Weight
NAV, Sc2	1.000
NAV, Sc8	-1.000

df	1
Sum of Squares	363.947
Mean Square	363.947
F-Value	3.959
P-Value	.0500
G-G	.0786
H-F	.0671

ROB ECDIS w/ Auto Positioning vs ROB Manual Positioning

	Cell Weight
NAV, Sc5	1.000
NAV, Sc6	-1.000

df	1
Sum of Squares	1948.965
Mean Square	1948.965
F-Value	21.201
P-Value	.0001
G-G	.0075
H-F	.0003

ROB ECDIS Manual Positioning vs Conventional Bridge

	Cell Weight
NAV, Sc6	1.000
NAV, Sc9	-1.000

df	1
Sum of Squares	244.352
Mean Square	244.352
F-Value	2.658
P-Value	.1070
G-G	.1059
H-F	.1180

OSL ECDIS Manual Positioning vs Conventional Bridge

	Cell Weight
NAV, Sc3	1.000
NAV, Sc8	-1.000

df	1
Sum of Squares	530.630
Mean Square	530.630
F-Value	5.772
P-Value	.0186
G-G	.0555
H-F	.0330

Both ECDIS w/ Auto Positioning vs Both ECDIS w/ Manual Positioning

	Cell Weight
NAV, Sc1	.500
NAV, Sc3	-.500
NAV, Sc5	.500
NAV, Sc6	-.500

df	1
Sum of Squares	3851.731
Mean Square	3851.731
F-Value	41.899
P-Value	.0001
G-G	.0012
H-F	.0001

All ECDIS w/ Auto Positioning vs Conventional Bridge

	Cell Weight
NAV, Sc1	.200
NAV, Sc2	.200
NAV, Sc4	.200
NAV, Sc5	.200
NAV, Sc7	.200
NAV, Sc8	-.500
NAV, Sc9	-.500

df	1
Sum of Squares	2270.093
Mean Square	2270.093
F-Value	24.694
P-Value	.0001
G-G	.0052
H-F	.0001

Figure E-3. Analysis of Variance (ANOVA) Tables and Single Degree of Freedom Contrasts for Workload Scores (cont.)

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	G-G	H-F
Subject	5	.544	.109				
Bridge Task	2	15200.753	7600.376	9.394	.0051	.0114	.0051
Bridge Task * S...	10	8090.714	809.071				
Scenario	8	.826	.103	1.000	.4512	.3632	.3632
Scenario * Subj...	40	4.128	.103				
Bridge Task * S...	16	6077.193	379.825	3.281	.0002	.0540	.0087
Bridge Task * S...	80	9260.174	115.752				

Dependent: Percent Time

Table of Epsilon Factors for df Adjustment
Dependent: Percent Time

	G-G Epsilon	H-F Epsilon
Bridge Task	.760	1.022
Scenario	.125	.125
Bridge Task * Scenario	.178	.437

NOTE: Probabilities are not corrected for values of epsilon greater than 1.

SINGLE DEGREE OF FREEDOM CONTRASTS

All ECDIS w/ Auto Positioning
vs Conventional Bridge

Effect: Bridge Task * Scenario
Dependent: Percent Time on Navigation

	Cell Weight
NAV, Sc1	.200
NAV, Sc2	.200
NAV, Sc4	.200
NAV, Sc5	.200
NAV, Sc7	.200
NAV, Sc8	-.500
NAV, Sc9	-.500

df	1
Sum of Squares	648.771
Mean Square	648.771
F-Value	5.605
P-Value	.0203
G-G	.0574
H-F	.0459

All ECDIS w/ Auto Positioning
vs Conventional Bridge

Effect: Bridge Task * Scenario
Dependent: Percent Time on Collision Avoidance

	Cell Weight
C/A, Sc1	.200
C/A, Sc2	.200
C/A, Sc4	.200
C/A, Sc5	.200
C/A, Sc7	.200
C/A, Sc8	-.500
C/A, Sc9	-.500

df	1
Sum of Squares	583.393
Mean Square	583.393
F-Value	5.040
P-Value	.0275
G-G	.0632
H-F	.0543

Figure E-4. Analysis of Variance (ANOVA) Tables and Single Degree of Freedom Contrasts for Percent of Time Spent on Bridge Tasks

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	G-G	H-F
Subject	4	.033	.008				
Navigation Phase	1	.008	.008	1.000	.3739	.3739	.3739
Navigation Phase * Subject	4	.033	.008				
Bridge Condition	2	.017	.008	1.000	.4096	.3739	.3739
Bridge Condition * Subject	8	.067	.008				
Primary Navigation Method	3	14255.758	4751.919	2.095	.1543	.2123	.2015
Primary Navigation Method * Subject	12	27216.367	2268.031				
Navigation Phase * Bridge Condition	2	.017	.008	1.000	.4096	.3739	.3739
Navigation Phase * Bridge Condition * Subject	8	.067	.008				
Navigation Phase * Primary Navigation Method	3	16969.758	5656.586	5.655	.0119	.0498	.0286
Navigation Phase * Primary Navigation Method * Subject	12	12003.033	1000.253				
Bridge Condition * Primary Navigation Method	6	48902.517	8150.419	16.133	.0001	.0007	.0001
Bridge Condition * Primary Navigation Method * Subject	24	12124.733	505.197				
Navigation Phase * Bridge Condition * Primary Navigation Method	6	7485.717	1247.619	3.399	.0143	.0990	.0586
Navigation Phase * Bridge Condition * Primary Navigation Method * Sub...	24	8808.867	367.036				

Dependent: primary method distrib.

Table of Epsilon Factors for df Adjustment
Dependent: primary method distrib.

	G-G Epsilon	H-F Epsilon
Navigation Phase	1.000	1.000
Bridge Condition	.500	.500
Primary Navigation Method	.417	.516
Navigation Phase * Bridge Condition	.500	.500
Navigation Phase * Primary Navigation Method	.480	.678
Bridge Condition * Primary Navigation Method	.389	.968
Navigation Phase * Bridge Condition * Primary Navigation Method	.282	.467

Figure E-5. Analysis of Variance (ANOVA) Tables and Single Degree of Freedom Contrasts for Primary Method of Navigation

SINGLE DEGREE OF FREEDOM CONTRASTS

Effect: Navigation Phase * Bridge Condition* Primary Navigation Method
Dependent: primary method distrib.

Primary Method of Navigation
in Coastal Waterway Segments
Indicated to be Radar/ARPA vs ECDIS
when ECDIS w/ Auto Positioning Available

	Cell Weight
Coastal, ECDIS Auto Positioning, Radar/ARPA	1.000
Coastal, ECDIS Auto Positioning, ECDIS	-1.000

df	1
Sum of Squares	8526.400
Mean Square	8526.400
F-Value	23.230
P-Value	.0001
G-G	.0082
H-F	.0024

Primary Method of Navigation
in Harbor/Harbor Approach Waterway Segments
Indicated to be Visual Piloting vs ECDIS
when ECDIS w/ Auto Positioning Available

	Cell Weight
Harbor/Harbor Approach, ECDIS Auto Positioning, Visual Piloting	1.000
Harbor/Harbor Approach, ECDIS Auto Positioning, ECDIS	-1.000

df	1
Sum of Squares	5856.400
Mean Square	5856.400
F-Value	15.956
P-Value	.0005
G-G	.0162
H-F	.0068

Figure E-5. Analysis of Variance (ANOVA) Tables and Single Degree of Freedom Contrasts for Primary Method of Navigation (cont.)

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	G-G	H-F
Subject	4	4.723	1.181				
Scenario	8	2.045	.256	1.212	.3237	.3481	.3266
Scenario * Subject	32	6.751	.211				

Dependent: Average Situational Awareness

Table of Epsilon Factors for df Adjustment
Dependent: Average Situational Awareness

	G-G Epsilon	H-F Epsilon
Scenario	.319	.933

Figure E-6. Analysis of Variance (ANOVA) Tables and Single Degree of Freedom Contrasts for Average Situational Awareness

Table E-2. Correlation Analyses Between Measures

Source	Correlation	P-Value	90% Lower	90% Upper	# of observations
Navigation workload score correlated with expert mariner-observer's tally of navigation errors	.330	.0486	.057	.558	36
Navigation workload score correlated with proportion of time spent on collision avoidance	-.575	.0002	-.736	-.352	36
Navigation workload score correlated with proportion of time spent on navigation	.508	.0013	.267	.689	36
Average situational awareness rating correlated with total number of chart re-creation drawing errors	-.126	.1158	-.253	.006	158
Average situational awareness rating correlated with total number of chart re-creation drawing errors for transit segments w/ ecdis used as primary method of navigation	-.244	.0370	-.419	-.053	73

Table E-3. ECDIS Features and Navigational Data Missed/Wanted

	Paper Chart Use	Charted Features Wanted on ECDIS	Navigational Data Wanted on ECDIS
		Scenario 1	
Mariner # 2	confirm buoy #, refer to personal notes re: call E/R	buoy/nav aid ID	time/dist info, SOG, CMG
M# 3		better navig. mark presentation	ARPA target vectors
M# 4	buoy # at 13 & 14, 17 & 18, verify targets as buoys, sounding on courseline	buoy #'s & symbols, soundings and other aids; more detail	course change alarm, chart change alarm, ETA to next waypoint, ARPA, time to go to cursor range & bearing, target vectors & #'s
		Scenario 2	
M# 2	check buoy #'s and other info	buoy #'s	ETA info, heading vector, course/dist b/w waypoints
M# 3	checked name of Chapel Hill channel, check Ambrose tower info	text naming Chapel Hill channel	ETA to waypoint
M# 4	soundings, buoy #'s	symbols	
M# 5	next course, buoy #'s, anchorage area	numerical indication of depths (assoc w/ contours)	courses, course & time to waypoint, ETA
M# 6	distance & bearing to Ambrose, buoy #'s, buoy lights, eyeballed anchorage position	buoy info	target info, ETA
		Scenario 3	
M# 2	check course, buoys, bearing to light tower	buoy/nav aid info (#'s)	set/drift adjustment when DRing
M# 3		used passage plan (?)	
M# 4	info, position, buoys, buoy #'s		courselines
		Scenario 4	
M# 2		nav aid ID data	CMG, SMG, set, drift
M# 3	check buoy name		
M# 4			
M# 5	check soundings, buoy #'s in Ambrose		variable vector line similar to Raytheon ARPA
M# 6	plot position (twice) in relation to Ambrose to check ETA, speed, & dist. to go		CPA & TCPA to cursor, ETA to waypoint
M# 7	check on aids at Ambrose, yellow buoy on ECDIS but not on chart	buoy names/ #'s	next course and distance as a way of monitoring entire route
		Scenario 5	
M# 2		buoy & geographic points ID data	
M# 3	check parallel		parallel indexing details
M# 5	check buoy #, sounding, check bridge span C-D	bridge info, sounding, anchorage location	extending vector line

Table E-3. ECDIS Features and Navigational Data Missed/Wanted (cont.)

	Paper Chart Use	Charted Features Wanted on ECDIS	Navigational Data Wanted on ECDIS
	Scenario 5 (cont.)		
Mariner # 6	ref. name Pt. Bonita, re. C-D span for Bay Br, change charts, water depth	bridge info	CPA & TCPA to cursor
M# 7	check bridge pier #'s, anchorage limits	outline of anchorage limits, buoy names/#'s, bridge pier #'s (letters)	radar/ARPA overlay
	Scenario 6		
M# 2			ANTS data in DR mode
M# 3	check position (twice), check parallel lands end		radar lock onto overlay, a buoy or other fixed object position
M# 4			variable VRM, range & bearing (?)
M# 5	plot fix at # 5 & 6		
M# 6	plot position (6x), check SF buoy, change chart		
M# 7		buoy names, #'s, point names	accurate position
	Scenario 7		
M# 2		text informaiton on buoys, etc.	proper CTS info
M# 3	check D tower, position (twice), position vs ECDIS, course bar channel, SF buoy		
M# 4	span info, course ref, waypoint ref (twice)	aid #'s, auto update to coastal/approach charts	
M# 5			targets
M# 6	course depth, wreck & bridge clearance, swingwide, precautionary area, change chart, MN ship channel, plot position (4x)		ETA to cursor
M# 7	buoy # for course change, buoy name (Hard. Rk), colregs demarcation line, check for buoy #8 (missing from ECDIS)	buoy names/#'s	radar/ARPA

Table E-4. Mean Cross-Track Distances For Scenario Comparisons

Location	Mean Cross-Track Distance of Scenarios Compared		t-Value	p-Value
San Francisco	**Scen5**	**Scen9**		
SF channel entrance	322.69	355.93	-0.61	0.58
Golden Gate Bridge	107.41	385.94	-3.07	0.05
Alcatraz	58.83	331.31	-2.44	0.09
Alcatraz 2nd turn	96.62	323.70	-2.28	0.06
San Francisco	**Scen5**	**Scen6**		
SF channel entrance	322.69	378.49	-0.88	0.41
SF channel - WP4	301.62	610.33	-1.12	0.31
Golden Gate Bridge	107.41	155.51	-0.38	0.72
San Francisco	**Scen6**	**Scen9**		
SF channel entrance	378.49	355.93	0.09	0.93
SF channel - WP4	610.33	355.97	-0.90	0.43
Golden Gate Bridge	155.51	385.94	-1.86	0.16
New York	**Scen2**	**Scen8**		
Sea Buoy	633.41	1090.41	-1.20	0.31
Ambrose 1st turn	112.67	150.93	-1.23	0.30
Ambrose 2nd turn	390.82	324.97	0.07	0.95
Verrazano Bridge	118.61	190.76	-1.71	0.18
New York	**Scen3**	**Scen8**		
Sea Buoy	470.49	1090.41	-4.48	0.04
Ambrose 1st turn	423.75	150.93	2.05	0.17
Ambrose 2nd turn	724.31	324.97	2.18	0.16
Verrazano Bridge	489.80	190.76	1.04	0.40
New York	**Scen3**	**Scen1**		
Sea Buoy	470.49	412.66	0.22	0.84
Ambrose 1st turn	423.75	134.29	2.93	0.09
Ambrose 2nd turn	724.31	195.77	12.39	0.006
Verrazano Bridge	489.80	57.69	2.02	0.18
New York	**Scen2**	**Scen1**		
Sea Buoy	633.41	412.66	0.36	0.75
Ambrose 1st turn	112.67	134.29	-0.05	0.96
Ambrose 2nd turn	390.82	195.77	0.94	0.42
Verrazano Bridge	118.61	57.69	0.92	0.42

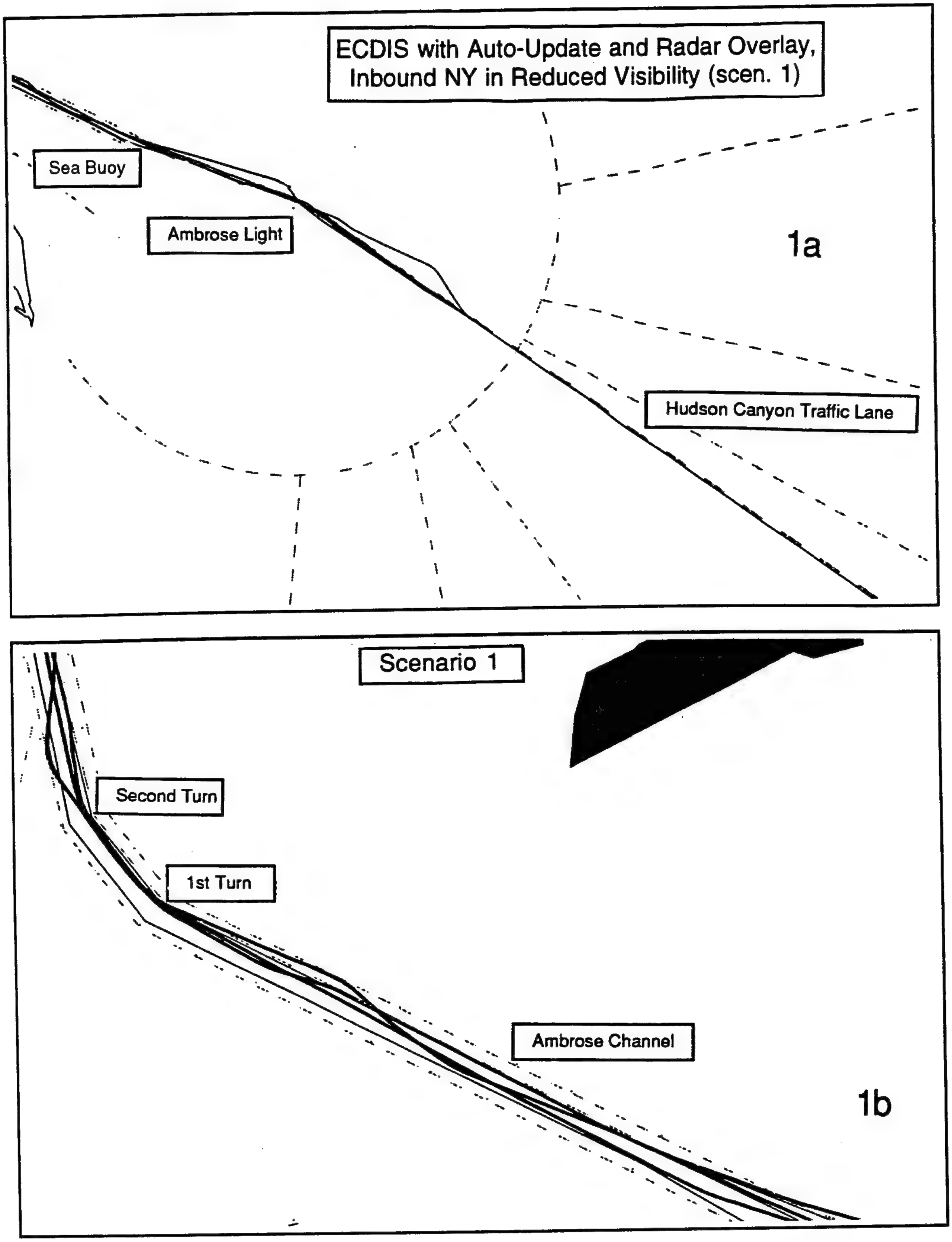


Figure E-7. Scenario 1 Composite Trackplots

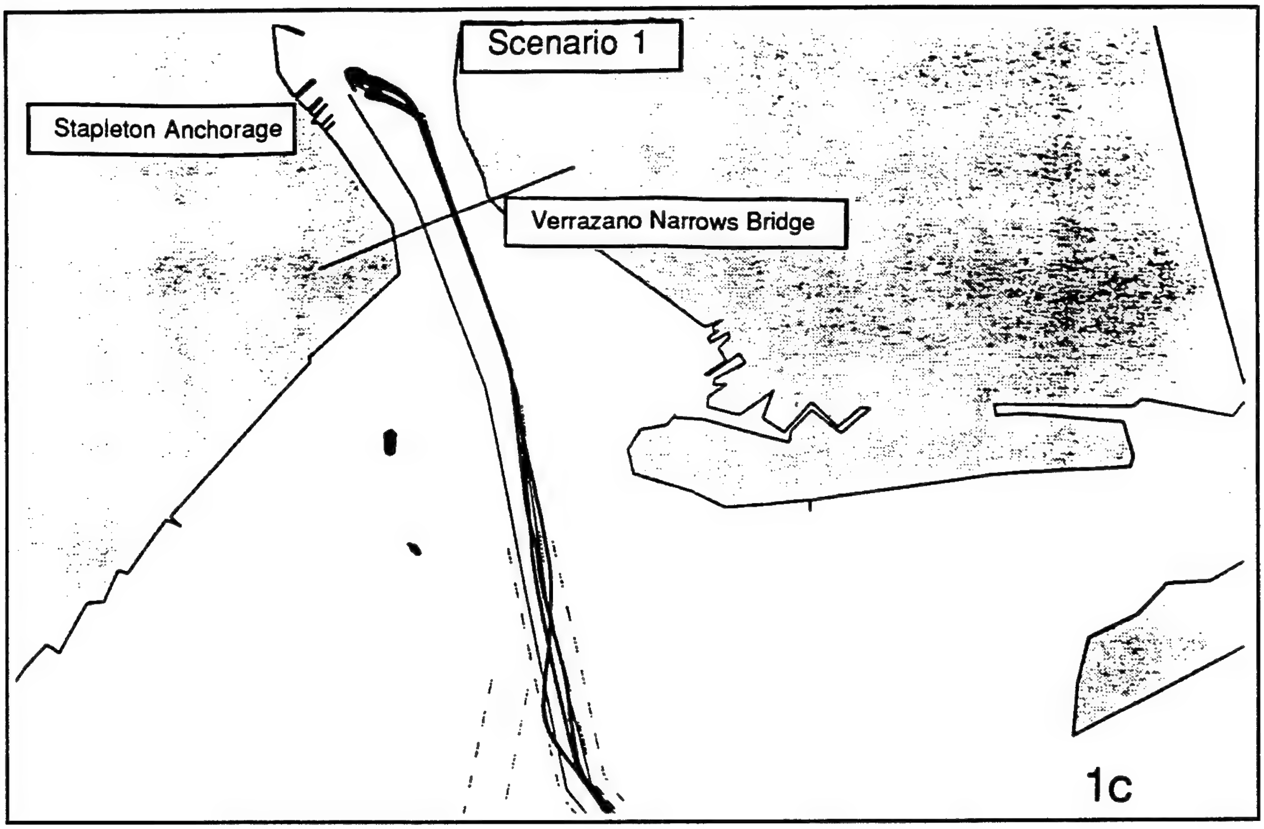


Figure E-7. Scenario 1 Composite Trackplots (cont.)

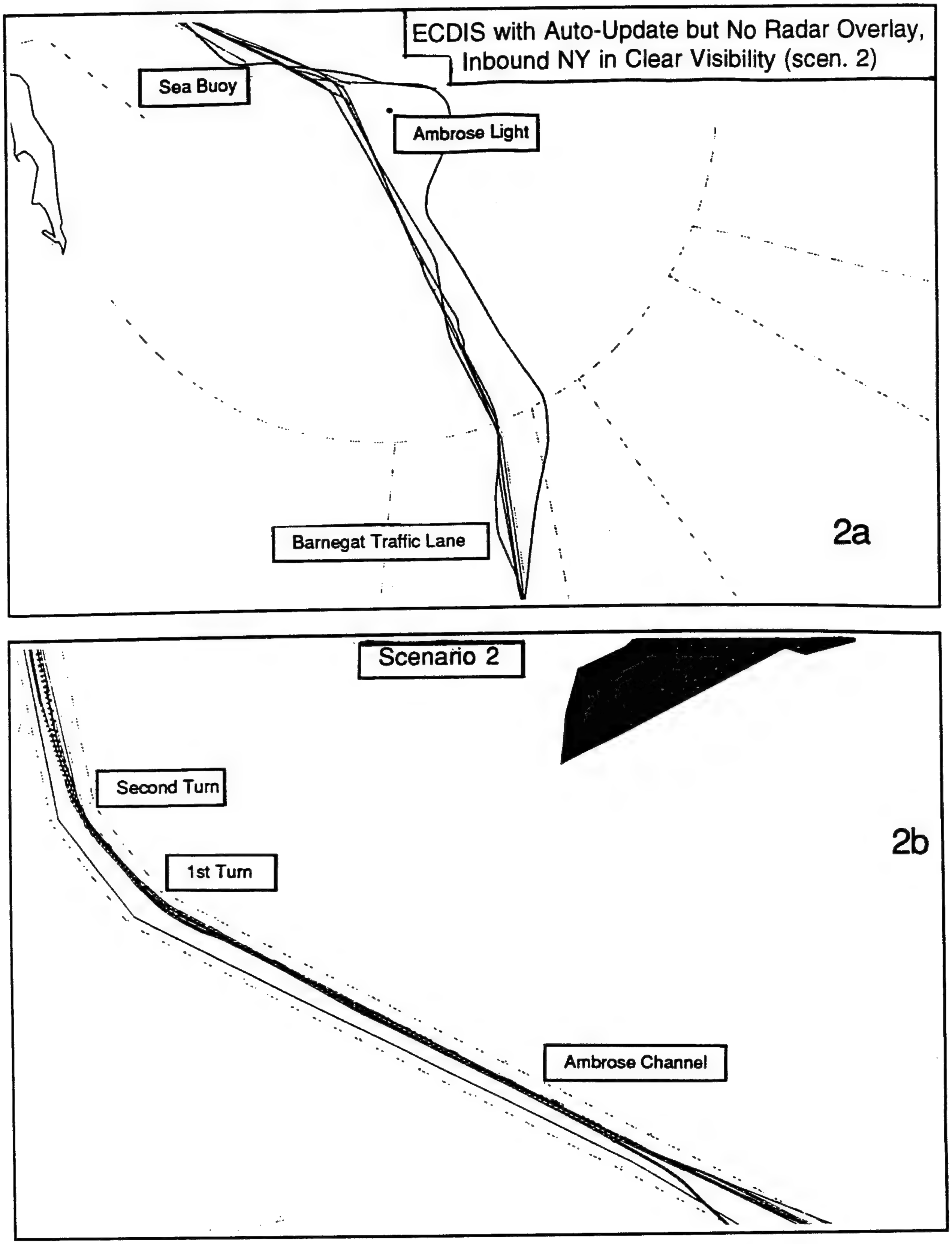


Figure E-8. Scenario 2 Composite Trackplots

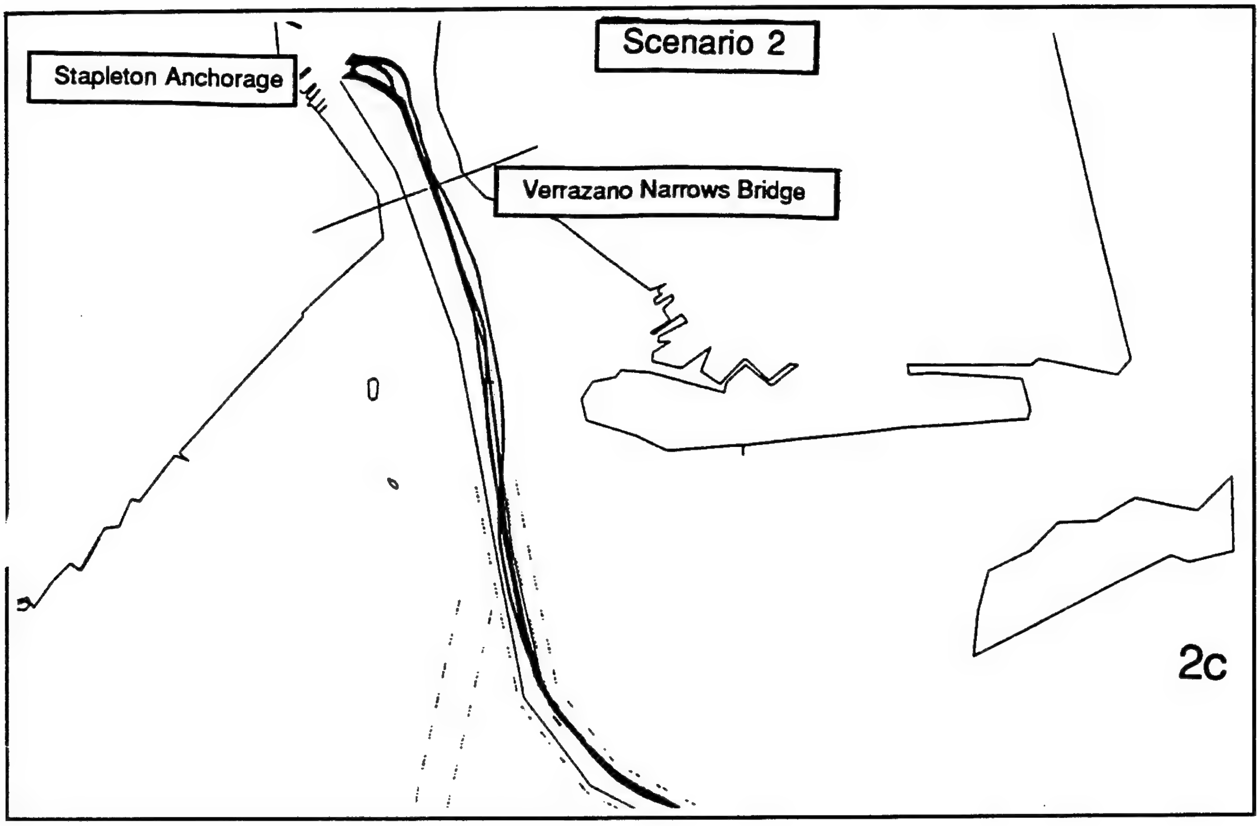


Figure E-8. Scenario 2 Composite Trackplots (cont.)

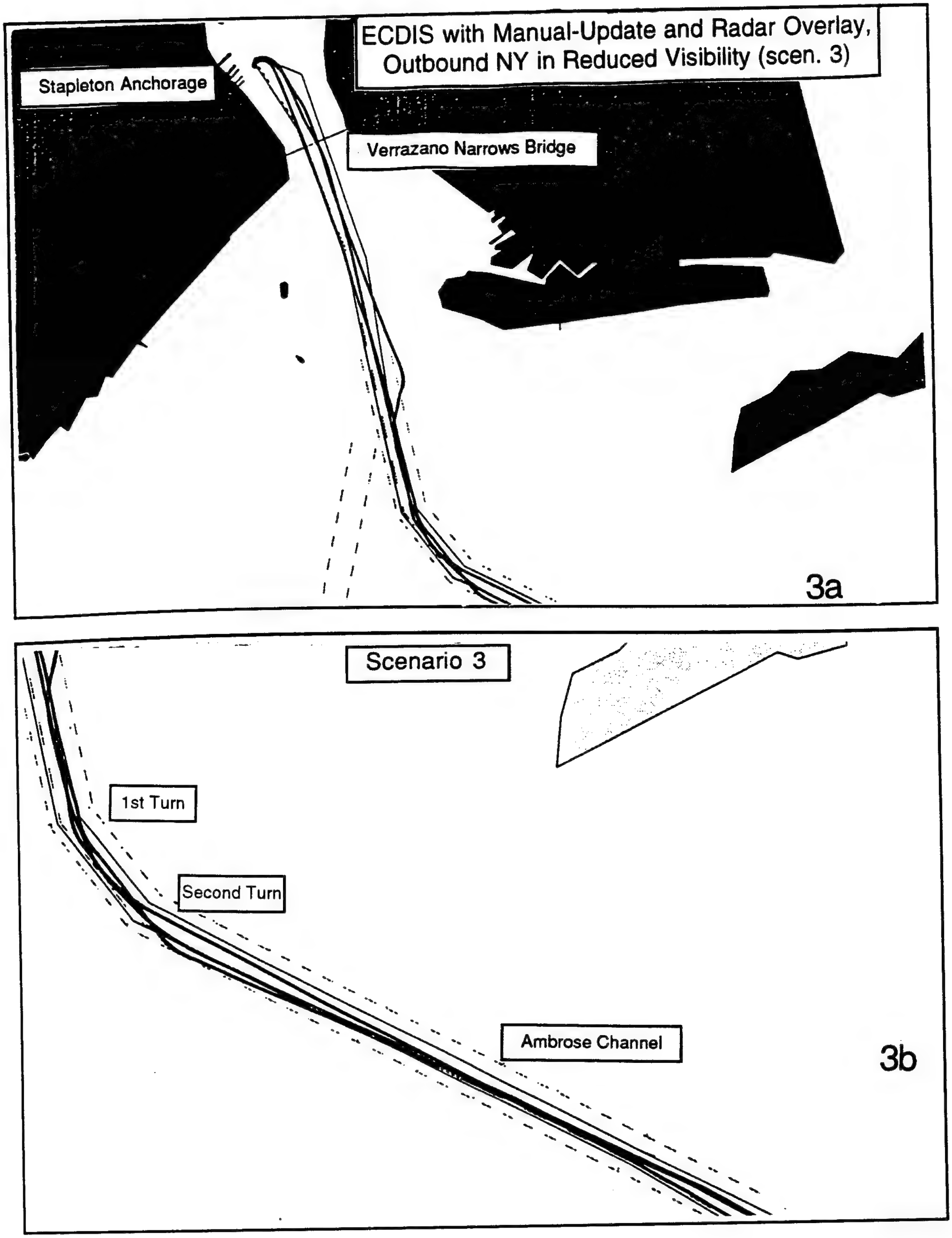


Figure E-9. Scenario 3 Composite Trackplots

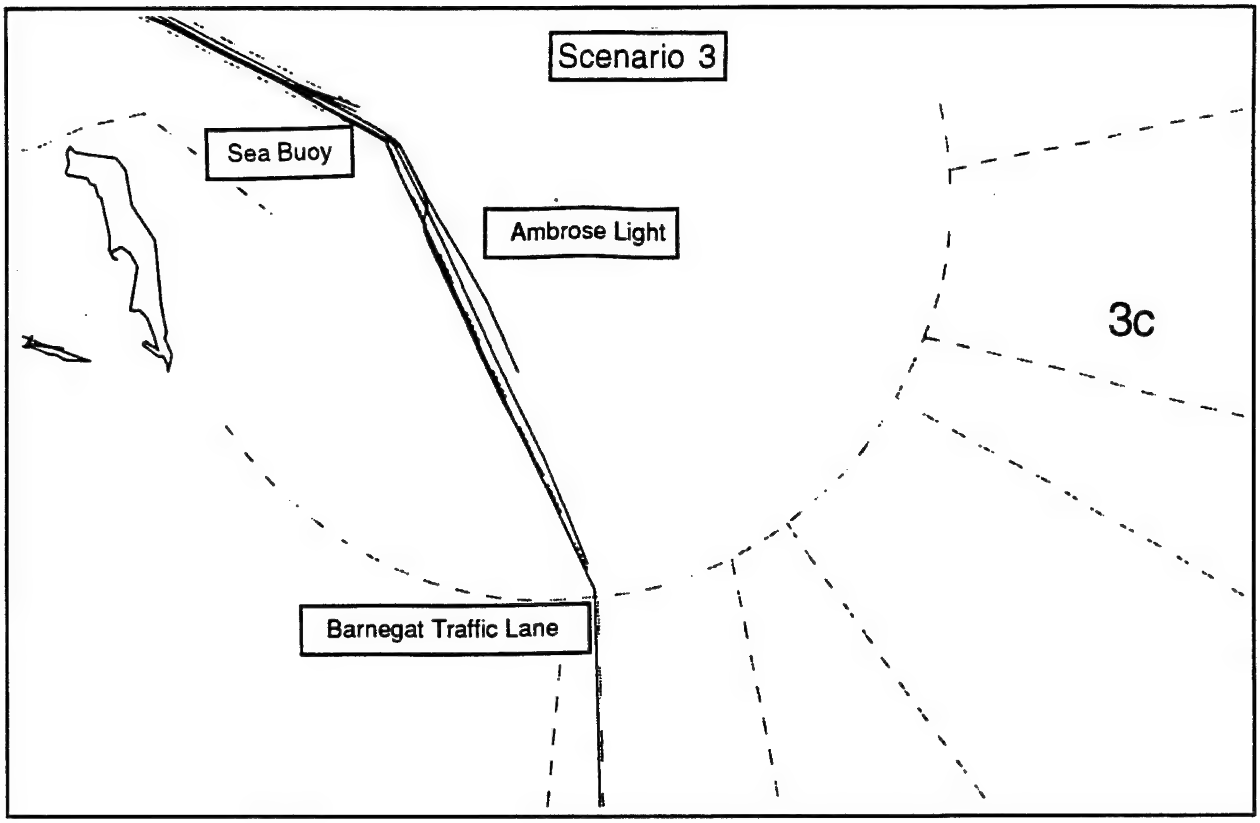


Figure E-9. Scenario 3 Composite Trackplots (cont.)

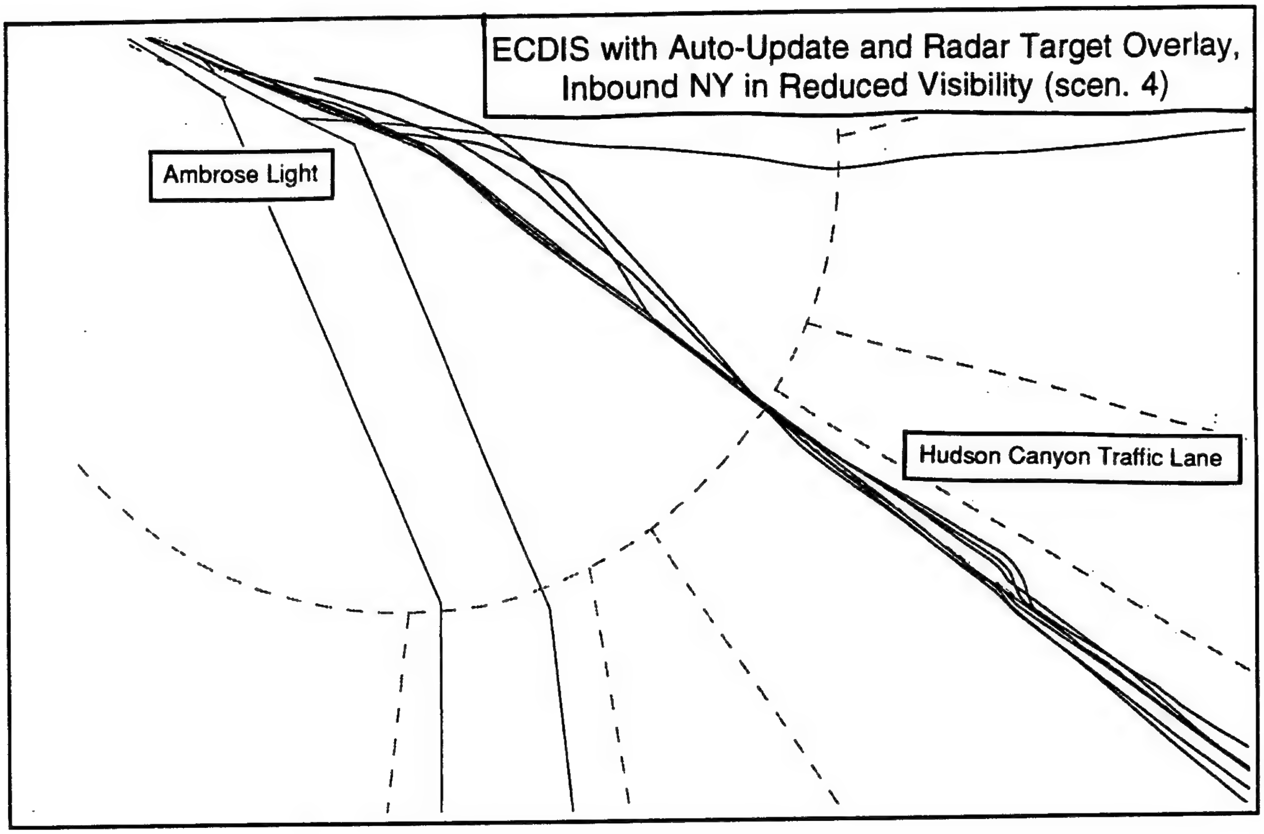


Figure E-10. Scenario 4 Composite Trackplot

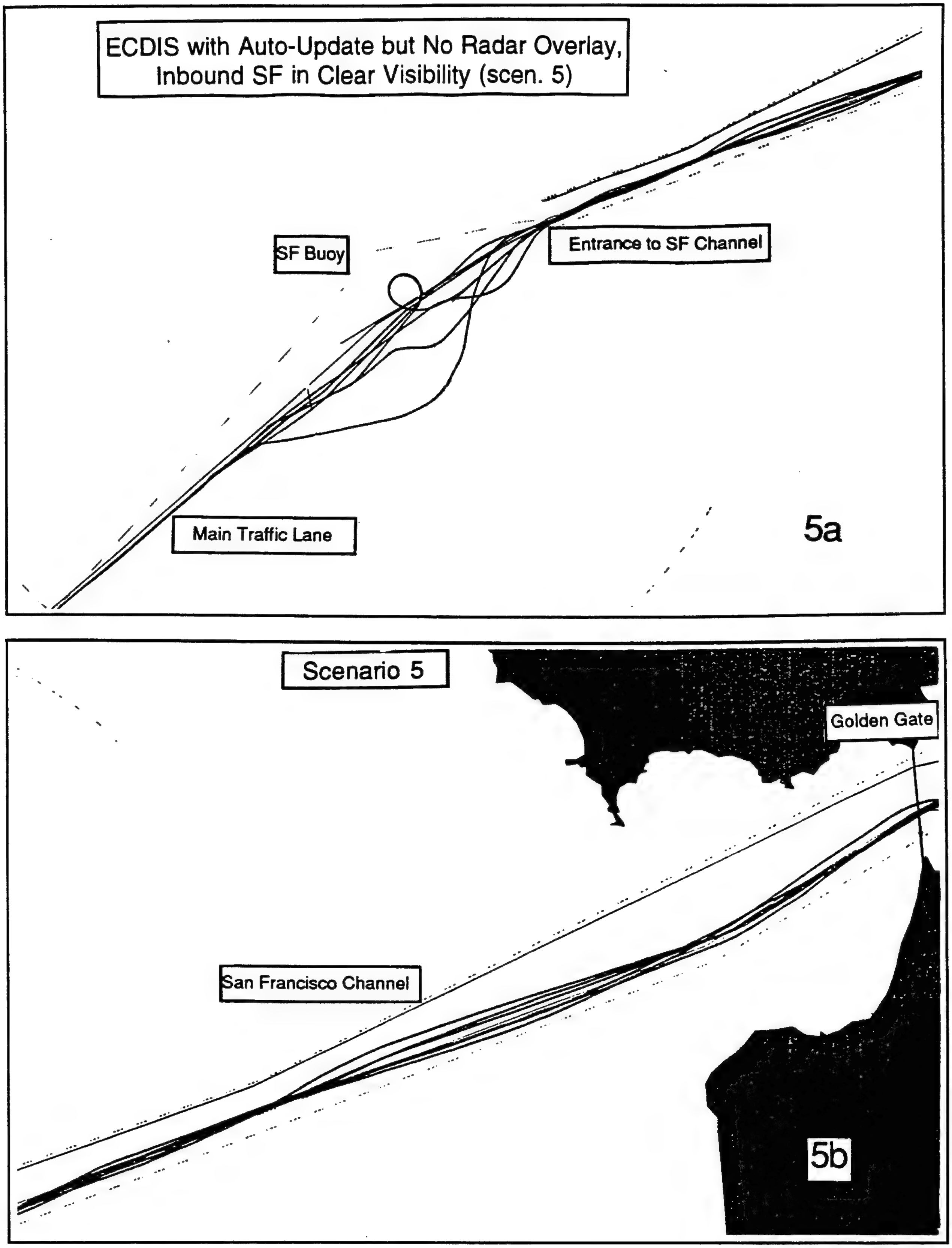


Figure E-11. Scenario 5 Composite Trackplots

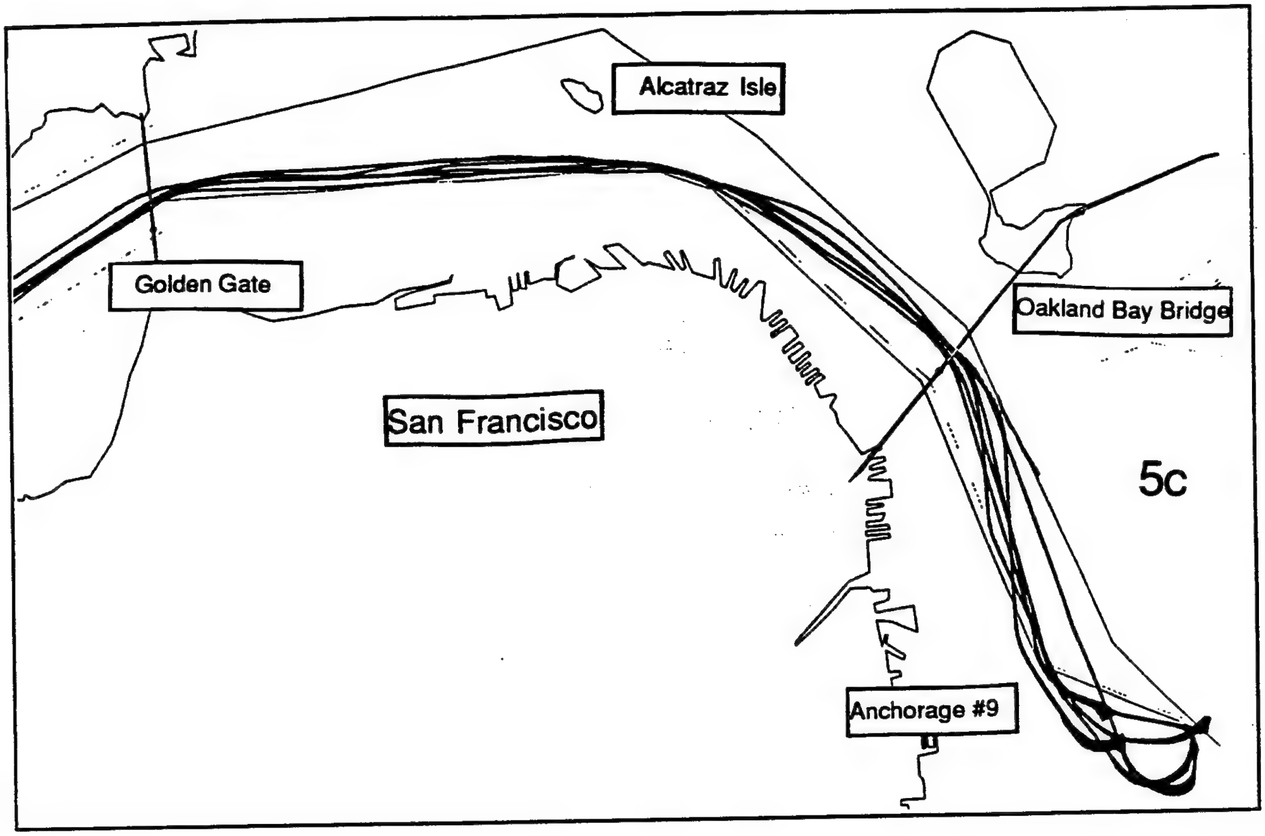
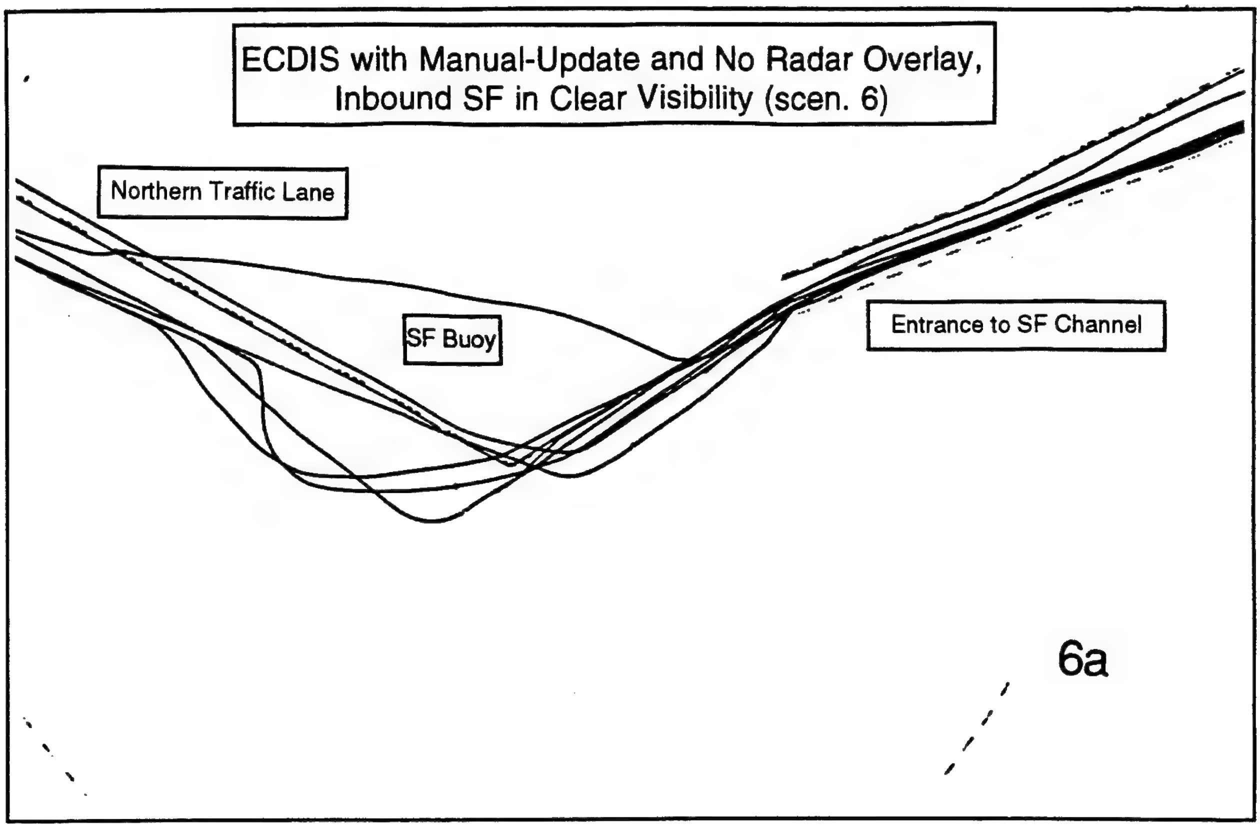


Figure E-11. Scenario 5 Composite Trackplots (cont.)



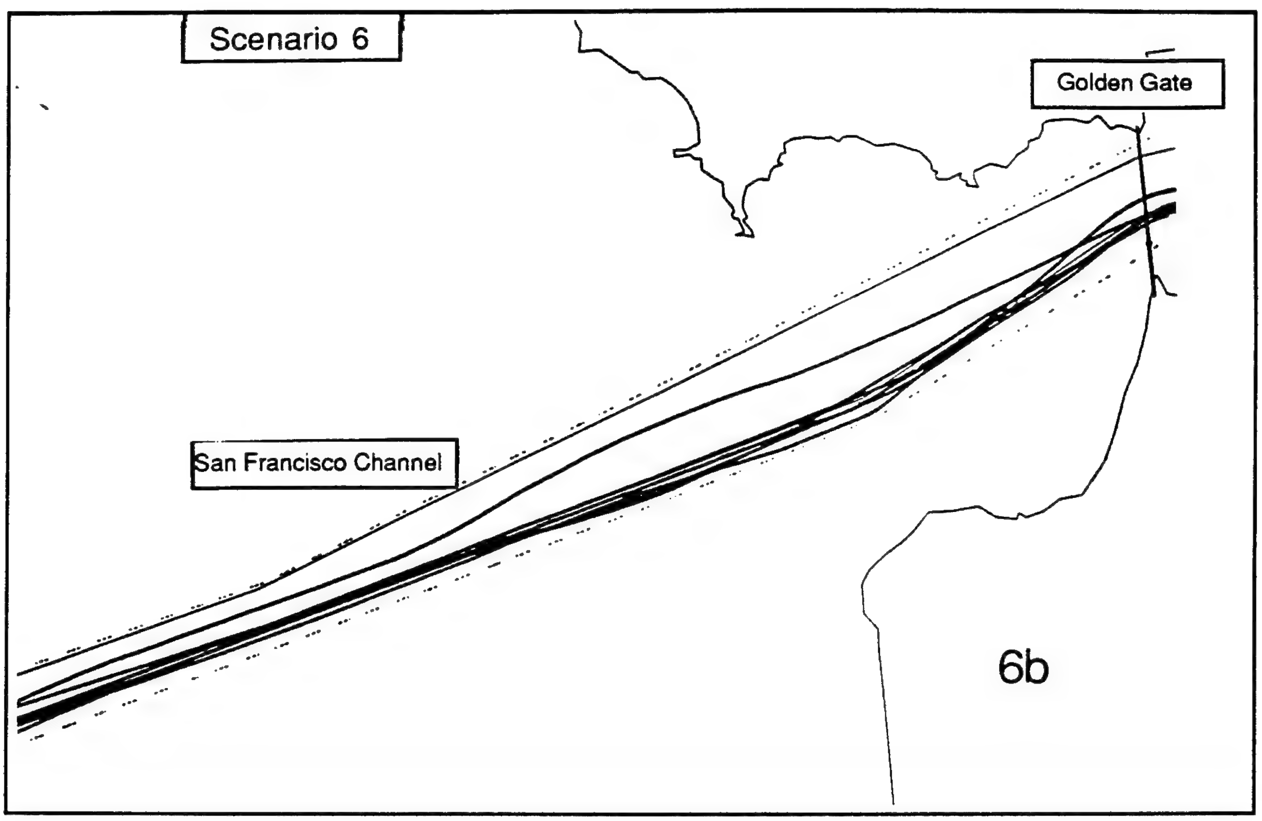


Figure E-12. Scenario 6 Composite Trackplots

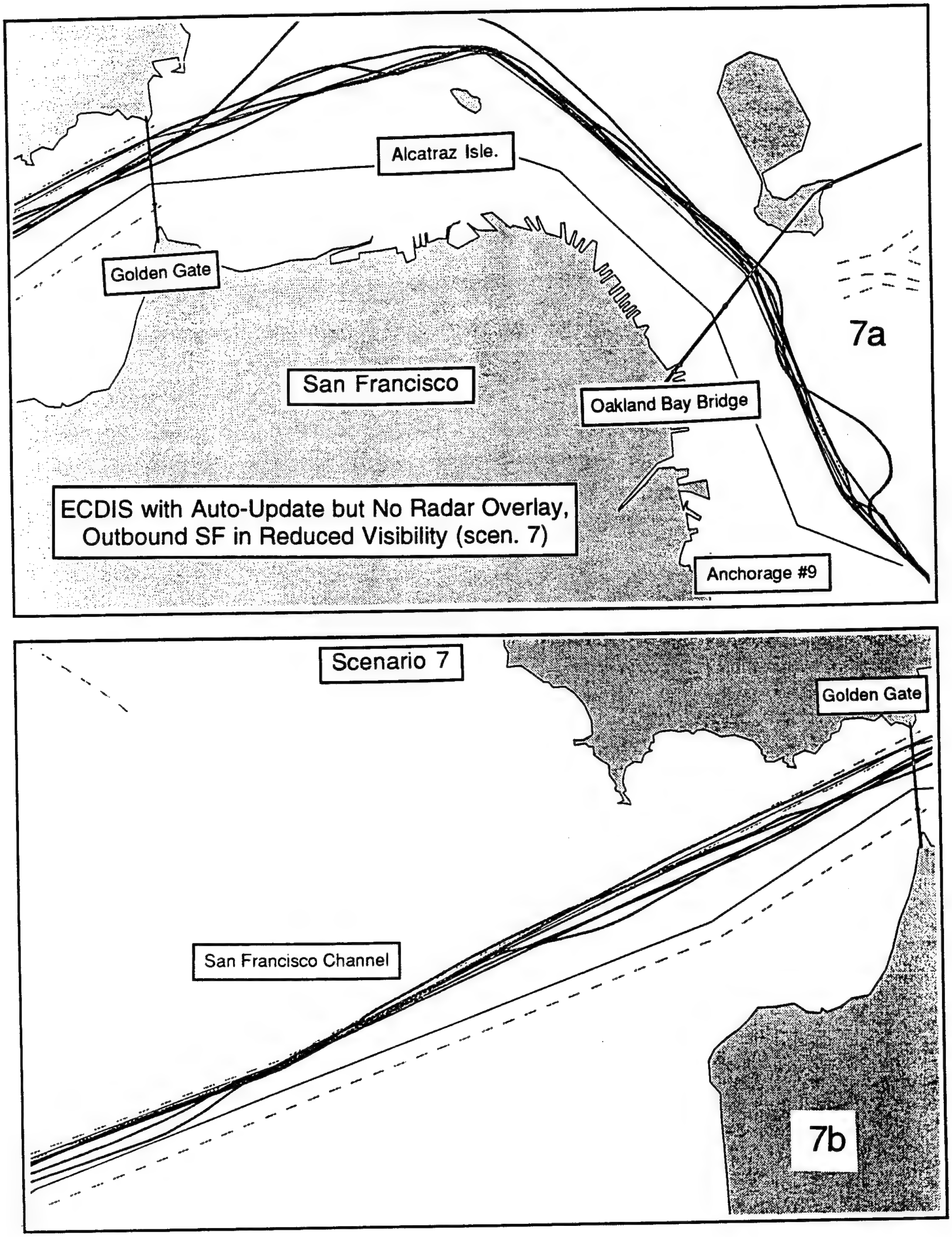


Figure E-13. Scenario 7 Composite Trackplots

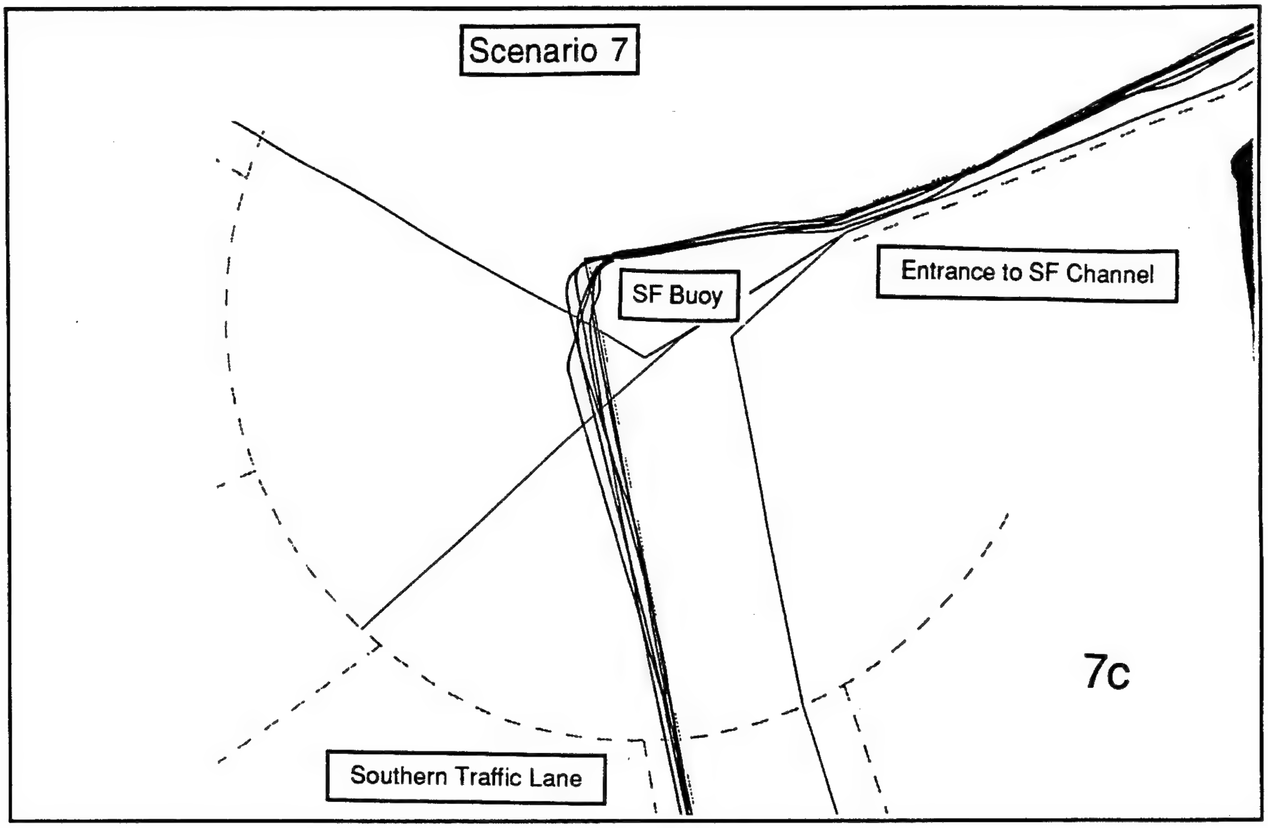
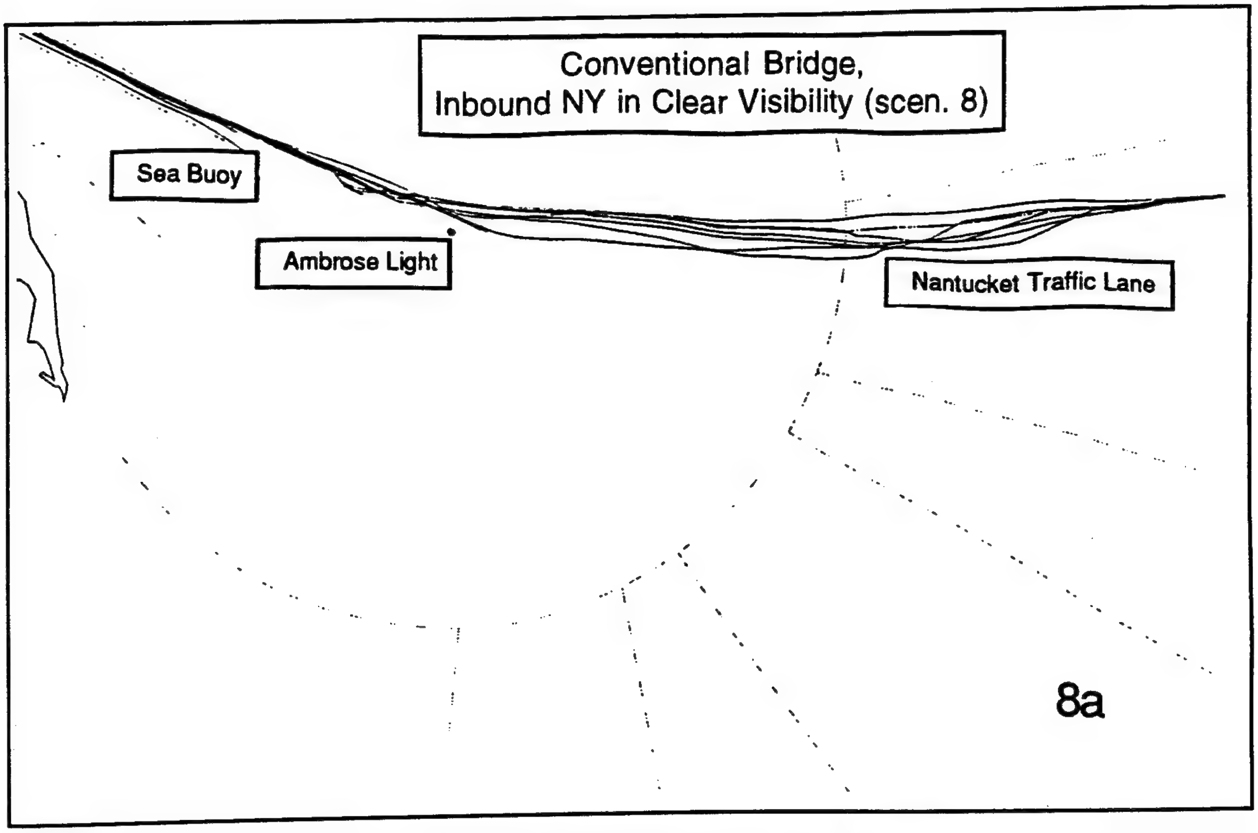


Figure E-13. Scenario 7 Composite Trackplots (cont.)



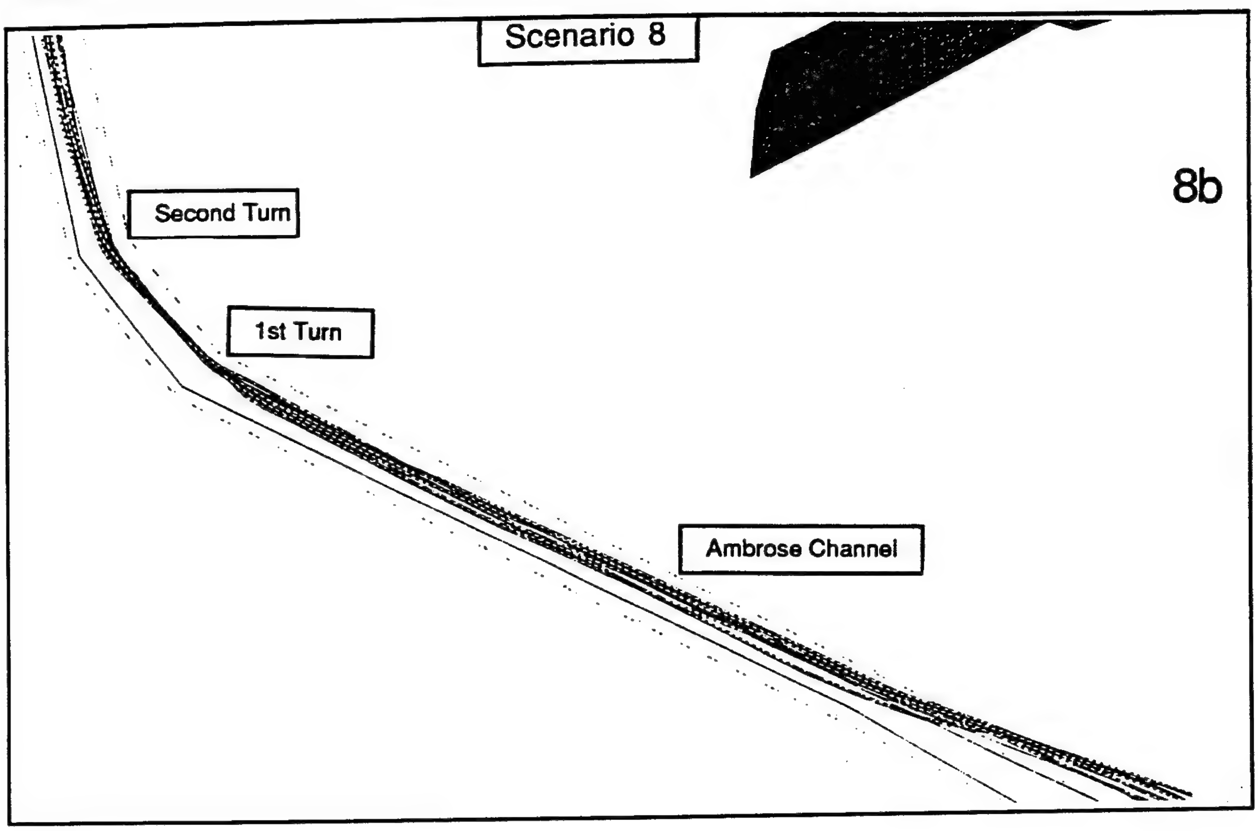


Figure E-14. Scenario 8 Composite Trackplots

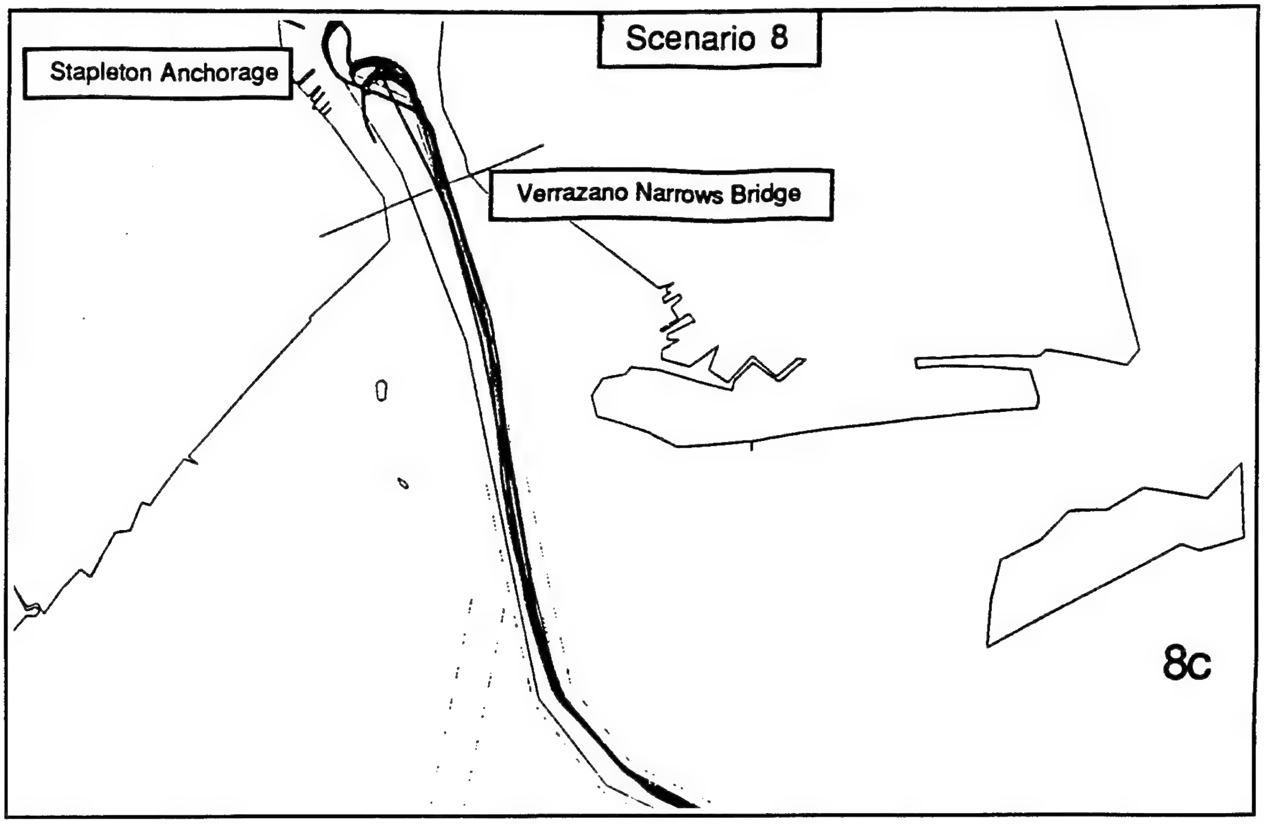


Figure E-14. Scenario 8 Composite Trackplots (cont.)

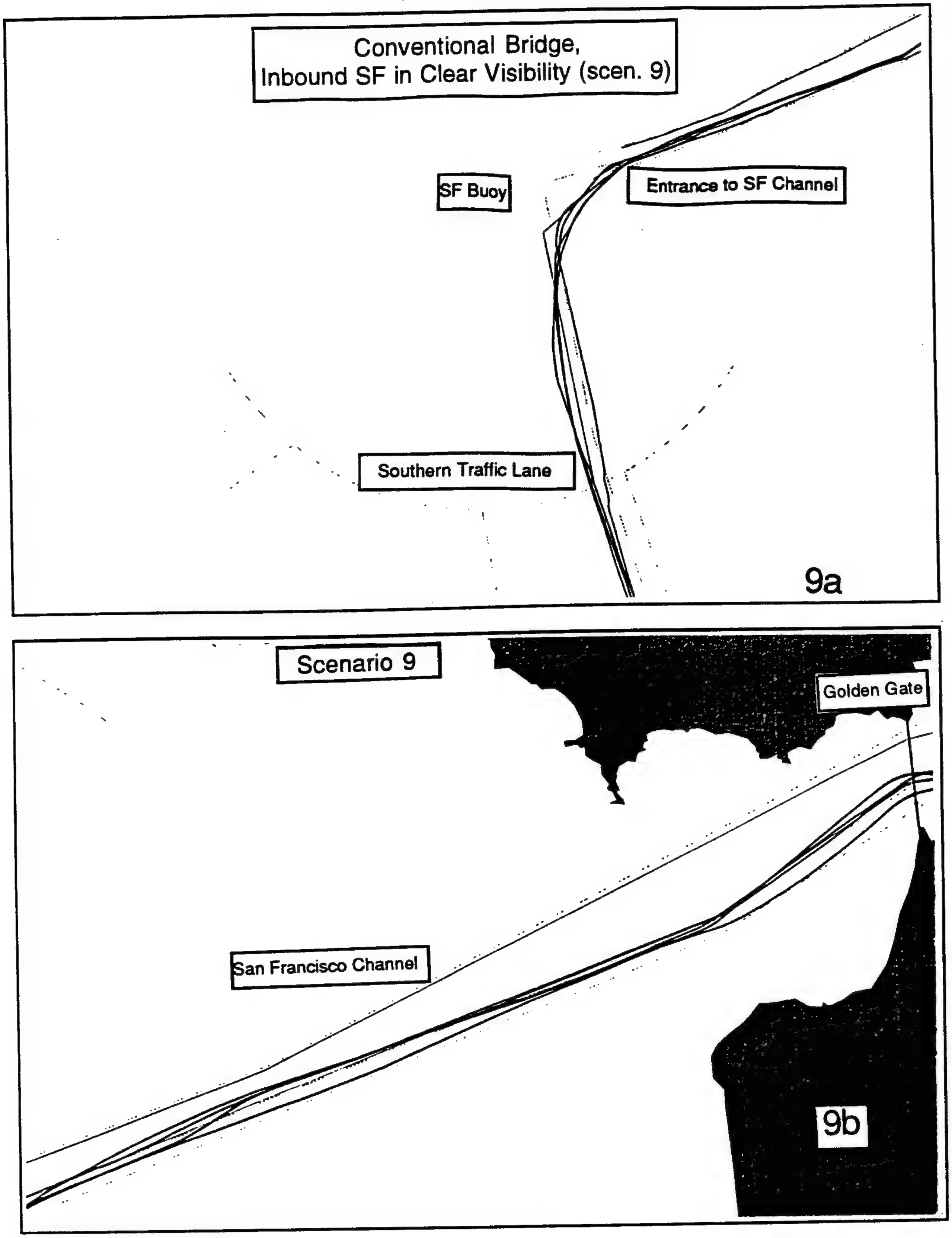


Figure E-15. Scenario 9 Composite Trackplots

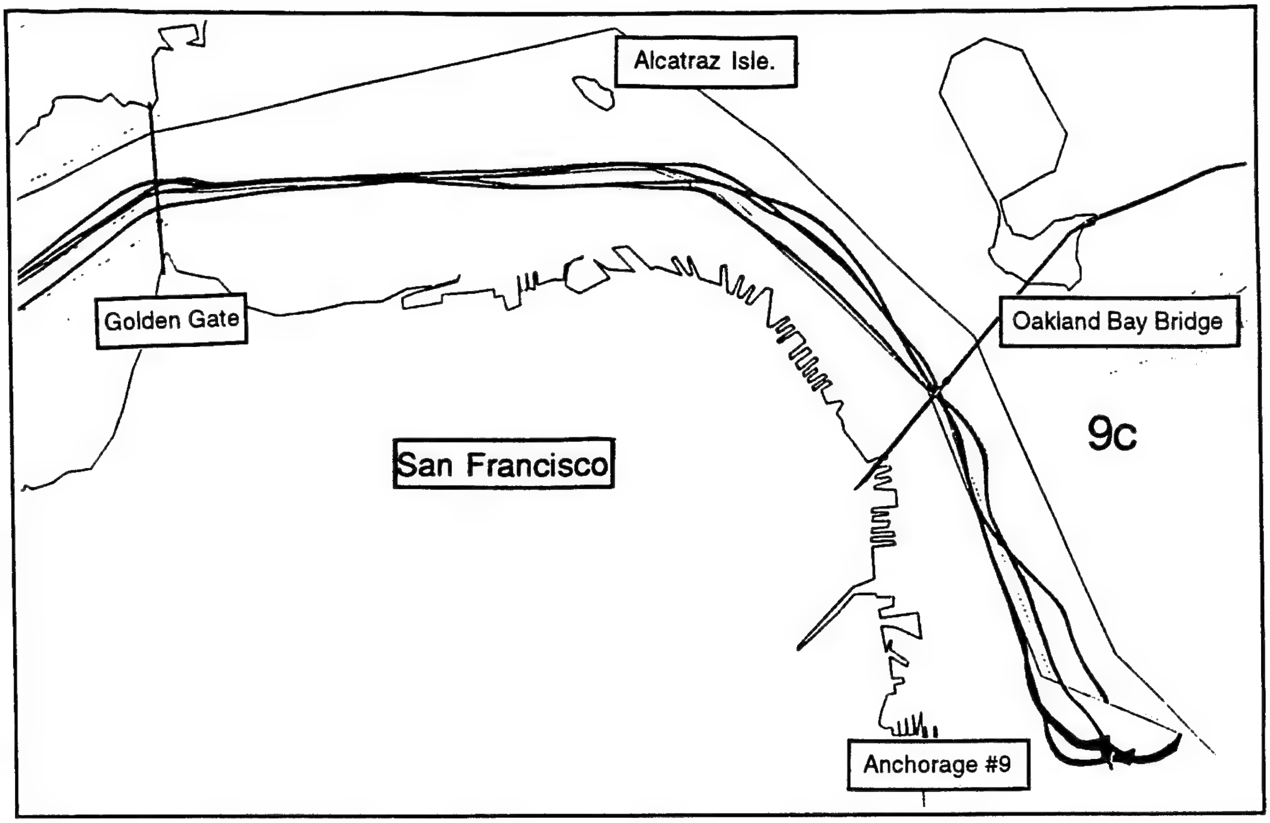


Figure E-15. Scenario 9 Composite Trackplots (cont.)

APPENDIX F.0
SUPPLEMENTARY MATERIAL FOR SECTION 8.0 CONCLUSIONS

The following is an annotated presentation of the Performance Standard for ECDIS (International Maritime Organization, September 1993), provided by the IMO/IHO Harmonization Group for ECDIS (HGE). In the table that follows, the Standards appear in the left-hand column, with each item in a box. To the right is a brief statement of findings from the experiment that are relevant to that item. For right-hand statements that represent a major discussion in the text, the section number is included.

Table F-1. Annotated Presentation of the Performance Standards for ECDIS

1. INTRODUCTION	
1.1 The primary function of the ECDIS is to contribute to safe navigation.	The simulator experiment demonstrated that the use of ECDIS can provide equivalent or greater safety to that provided by the use of the paper chart and conventional procedures during route monitoring. Two mechanisms to provide this safety were identified: 1.) decreased cross track distance from the planned route and 2.) an increased proportion of time spent on "look out" and collision avoidance. (Section 5.3)
1.2 ECDIS may be accepted as an equivalent complying with the up-to-date chart required by regulation V/20 of the 1974 SOLAS Convention.	Difficulties with the accuracy of privately digitized electronic charts support the importance of hydrographic offices producing or taking responsibility of electronic charts if they are to be a legal equivalent. (Section 6.1)
1.3 In addition to the general requirements for shipborne radio equipment forming part of the global maritime distress and safety system (GMDSS) and for electronic navigational aids contained in IMO resolution A.694(17), ECDIS should meet the requirements of this performance standard.	
1.4 ECDIS should be capable of displaying all chart information necessary for safe and efficient navigation, originated by, and distributed on the authority of, government authorized hydrographic offices.	Difficulties with the accuracy of privately digitized electronic charts support the importance of hydrographic offices producing or taking responsibility of electronic charts if they are to be a legal equivalent. (Section 6.1)
1.5 ECDIS should facilitate simple and reliable updating of the electronic navigational chart.	
1.6 ECDIS should reduce the navigational workload compared to using the paper charts. It should enable the mariner to execute in a convenient and timely manner all route planning, route monitoring and positioning currently performed on paper charts. It should be capable of continuously plotting the ship's position.	The simulator experiment demonstrated that the use of ECDIS can reduce the navigation workload during route monitoring compared to using the paper chart and radar and visual piloting techniques. The major factor in the reduction in workload is the automation of position fixing that allows navigation "at a glance." (Section 5.3) Observed reductions in workload were dependent on continuous updating of the ship's position. (Section 5.4)

1.7 ECDIS should have at least the same reliability and availability of presentation as the paper chart published by government authorized hydrographic offices.	
1.8 ECDIS should provide appropriate alarms or indications with respect to the information displayed or malfunction of the equipment. (see appendix 5)	Warnings were among the features most frequently recommended by the participating mariners. (Section 6.4)

2. DEFINITIONS	
2.1 For the purpose of this performance standard.	
2.1.1 **Electronic Chart Display and Information System (ECDIS)** means a navigation information system which can be accepted as complying with the up-to-date chart required by regulation V/20 of the 1974 SOLAS Convention, by displaying selected information from a system electronic navigational chart (SENC) with positional information from navigation sensors to assists the mariner in route planning and route monitoring, and if required display additional navigation-related information.	Difficulties with the accuracy of privately digitized electronic charts support the importance of hydrographic offices producing or taking responsibility of electronic charts if they are to be a legal equivalent. (Section 6.1) Both objective data and mariners opinions strongly support the requirement of automatic position fixing for route monitoring. (Section 5.4) Mariners asked for specific items and expressed a need for additional, supplemental information (available in such a way that it would not clutter the screen during route monitoring). (Section 6.3, 6.4, 8.4)
2.1.2 **Electronic Navigational Chart (ENC)** means the database, standardized as to content, structure and format, issued for use with ECDIS on the authority of government authorizes hydrographic offices. The ENC contains all the chart information necessary for safe navigation and may contain supplementary information in addition to that contained in the paper chart (e.g. sailing directions) which may be considered necessary for safe navigation.	While using electronic chart digitized by two commercial companies, simulator engineers and mariners found enough problems so that they would strongly recommend that all ENCs be done on authority of national hydrographic offices. (Section 6.1) Mariners strongly supported supplementary material that is easily available "at user's option." (Section 6.3)

2.1.3 **System Electronic Navigational Chart (SENC)** means a data base resulting from the transformation of the ENC by ECDIS for appropriate use, updates the ENC by appropriate means, and other data added by the mariner. It is this data base that is actually accessed by the ECDIS for display generation and other navigational functions and is equivalent to an up-to-date paper chart. The SENC may also contain information from other sources.	Mariners strongly supported supplementary material that is easily available "at user's option." (Section 6.3)
2.1.4 **Standard Display** means the level of ENC information that should be shown when a chart is first displayed on the ECDIS. Depending upon the needs of the mariner, the level of the information it provides for route planning or route monitoring may be modified by the mariner.	The list of features most frequently used or recommended by the mariners is included in the Standard Display. (Section 6.3, 8.4) Mariners strongly supported the capability to modify the presentation at user's option. (Section 6.3, 8.4) Several mariners mentioned a need for a "panic button" that would return the display to something immediately usable.
2.1.5 **Display Base** means the level of SENC information which cannot be removed from the display, consisting of information which is required at all times, in all geographic areas, and all circumstance. It is not intended to be sufficient for safe navigation.	
2.2 Further information on definitions may be found in IHO Special Publication S-52, appendix 3 (see appendix 1).	

3. DISPLAY OF SENC INFORMATION	
3.1 The ECDIS should be capable of displaying all SENC information.	

3.2 SENC information available for display during route planning and route monitoring should be subdivided into the following three categories: Display Base Standard Display All Other Information (see appendix 2)	Mariners preferred a simple display for route monitoring, one that outlined safe water. They strongly supported the capability to easily reference additional information. (Section 6.3, 8.4) Experimenters' tallies and extensive questionnaires reporting mariners use and recommendations for specific chart features to be displayed for route monitoring are presented in the main report. (Section 6.3, 8.4)
3.3 The ECDIS should present the Standard Display at any time by a single operator action.	Several mariners mentioned a need for a "panic button" that would return the display to something immediately usable. A concern for standardization of systems also supports a "standard" display.
3.4 When a chart is first displayed on the ECDIS, it should provide the Standard Display at the largest scale available in the SENC for the displayed area.	In the Harbor/Harbor Approach phase of navigation, mariners most frequently selected scales in the 1:20,000 to 1:50,000 range. Occasionally. they zoomed to larger scales. (Section 6.2)
3.5 It should be easy to add or remove information from the ECDIS display. It should not be possible to remove information contained in the Display Base.	The mariners tended to prefer a relatively simple display for route monitoring. Also, they were generally in favor of "at user's option" in the selection of features. (Section 6.3, 8.4)
3.6 It should be possible for the mariner to select a safety contour from the depth contours provided by the SENC. ECDIS should emphasize the safety contour over other contours on the display.	
3.7 It should be possible for the mariner to select a safety depth. The ECDIS should emphasize soundings equal to or less than the safety depth whenever spot soundings are selected for display.	How a safety depth should be displayed was a major concern. Several recommended that soundings or contours be expressed in terms of underkeel clearance for own ship, rather than absolute depth. One wanted underkeel clearance calculated for speed of own ship. (Section 6.3)
3.8 The ENC and all update information should be displayed without degradation of their information content.	
3.9 The system should provide a method to ensure the ENC and all updates to it have been correctly loaded into the SENC.	

3.10 The ENC data and updates to it should be clearly distinguishable from other displayed information, such as, for example, that lists in appendix 3.	

4. PROVISION AND UPDATING OF CHART INFORMATION	
4.1 The chart information to be used in ECDIS should be the latest edition of that originated by a government authorized hydrographic office, and conform to IHO standards.	
4.2 The contents of the SENC should be adequate and up-to-date for the intended voyage to comply with regulation V/20 of the 1974 SOLAS Convention.	
4.3 It should not be possible to alter the contents of the ENC.	
4.4 Updates should be stored separately from the ENC.	
4.5 The ECDIS should be capable of accepting official updates to the ENC data provided in standard IHO format. These updates should be automatically applied to the SENC. By whatever means updates are received, the implementation procedure should not interfere with the display in use.	
4.6 The ECDIS should also be capable of accepting updates to the ENC data entered manually with simple means for verification prior to the final acceptance of the data. They should be distinguishable on the display from ENC information and its official updates and not affect its legibility.	
4.7 ECDIS should keep a record of updates including time of application to the SENC.	
4.8 ECDIS should allow the mariner to display updates in order to view their contents and to ascertain that they have been included in the SENC.	

5. SCALE	
The ECDIS should provide an indication if: .1 the information is displayed at a larger scale than that contained in the ENC; or .2 own ship's position is covered by an ENC at a larger scale than that provided by the display, a warning should be provided.	Mariners did not appear to understand the implications of scale. This is an matter for training as well as warnings.

6. DISPLAY OF OTHER INFORMATION	
6.1 Radar information or other navigational information may be added to the ECDIS display. However, it should not degrade the SENC information and it should be clearly distinguishable from the SENC information.	Mariners' concerns with the clarity and clutter of the integrated displays that they saw support this item. (Section 7.2)
6.2 ECDIS and added navigational information should use a common reference system. If this is not the case, an indication should be provided.	
6.3 Radar	
6.3.1 Transferred radar information may contain both the radar image and ARPA information.	Mariners wanted a complete, high fidelity radar/ARPA both for navigation and for collision avoidance. This need makes integration a complex issue beyond the scope of this Standard. (Section 7.2)
6.3.2 If the radar image is added to the ECDIS display, the chart and the radar image should match in scale and in orientation.	
6.3.3 The radar image and the position from the position sensor should both be adjusted automatically for antenna offset from the conning position.	The match between radar and chart image was an important factor in mariner confidence. Some saw it as the primary value of a radar overlay. (Section 7.2)
6.3.4 It should be possible to adjust the displayed position of the ship manually so that the radar image matches the SENC display.	

6.3.5 It should be possible to remove the radar information by single operator action.	In questionnaires, mariners recommended flexibility and user's option in how the integration was presented. (Section 7.2)

7. DISPLAY MODE AND GENERATION OF THE NEIGHBORING AREA	
7.1 It should always be possible to display the SENC in a "north-up" orientation. Other orientations are permitted.	Of the mariners who expressed a preference, it was for north-up.
7.2 ECDIS should provide for true motion mode. Other modes are permitted.	Mariners wanted both true and relative motion, especially for use in traffic.
7.3 When true motion mode is in use, reset and generation of the neighboring area should take place automatically at a distance from the border of the display determined by the mariner.	Mariners supported any features that resulted in "hands off" navigation.
7.4 It should be possible to change manually the chart area and the position of own ship relative to the edge of the display.	Mariners felt that this was an important feature for "look ahead."

8. COLOURS AND SYMBOLS	
8.1 IHO recommended colours and symbols should be used to represent ENC information. (IHO Special Publication S-52, appendix 2) (see appendix 1)	
8.2 The colours and symbols other than those mentioned in 8.1 should be those used to describe the navigational elements and parameters listed in appendix 3 and published by IEC Publication 1174.	
8.3 SENC information when displayed at the scale specified in the ENC should use the specified size of symbols, figures and letters. (IHO Special Publication S-52, appendix 2 - see appendix 1 and IEC Publication 1174)	
8.4 The ECDIS should allow the mariner to select whether own ship is displayed in true scale or as a symbol.	After seeing both scaled and unscaled ship' symbols in Harbor/Harbor Approach operations, mariners strongly preferred a scaled symbol. (Section 6.4)

9. DISPLAY REQUIREMENTS	
9.1 ECDIS should be capable of displaying information for: .1 route planning and supplementary navigation tasks .2 route monitoring	The findings of the experiment supported the substantial value of ECDIS for route monitoring. (Section 5.0) Both a second chart view and the capability to offset the image of own ship were valued for look ahead.
9.2 The effective size of the chart presentation for route monitoring should be at least 270 mm by 270 mm.	The mariners were satisfied with this chart size. But they saw it with the availability of a second chart presentation set at a smaller scale for look ahead or set at a larger scale for greater resolution. (Section 6.2)
9.3 The display should be capable of meeting colour and resolution recommendations of IHO.	
9.4 The method of presentation should ensure that the displayed information is clearly visible to more than one observer in the conditions of light normally experienced on the bridge of the ship by day and by night.	

10. ROUTE PLANNING, MONITORING AND VOYAGE RECORDING	
10.1 It should be possible to carry out route planning and route monitoring in a simple and reliable manner.	The study considered only route monitoring. Performance is described in Section 5.3 ,5.4, Features and functions used or recommended are described in Section 6.3, 6.4.
10.2 ECDIS should be designed following ergonomic principles for user-friendly operation.	The simulator experiment examined the mariner's preferences for system features to be used during route monitoring. (Section 6.3) It did not examine more generic operator/computer interface issues. (Section 8.7)
10.3 The largest scale data available in the SENC for the area given, shall always be used by the ECDIS for all alarms and indications of crossing the ship's safety contour and of entering a prohibited area, and for alarms and indications according to Appendix 4.	

10.4 Route Planning	
10.4.1 It should be possible to carry out route planning including both straight and curved segments.	
10.4.2 It should be possible to adjust a planned route by, for example: .1 Adding waypoints to a route; .2 Deleting waypoints from a route; .3 Changing the position of a waypoint; .4 Changing the order of the waypoints in the route.	
10.4.3 It should be possible to plan alternate routes in addition to the selected route. The selected route should be clearly disting-uishable from the other route.	
10.4.4 An indication is required if the mariner plans a route across an own ship's safety contour.	
10.4.5 An indication is required if the mariner plans a route across the boundary of a prohibited area or a geographic area for which special conditions exist. (See Appendix 4)	
10.4.6 It should be possible for the mariner to specify a limit of deviation from the planned route at which activation of the automatic offtrack alarm should occur.	
10.5 Route Monitoring	
10.5.1 For route monitoring the selected route and own ship's position should appear whenever the display covers that area.	

10.5.2 It should be possible to display a sea area that does not have the ship on the display (e.g. for look ahead, route planning) while route monitoring. If this is done on the display used for route monitoring functions (e.g. updating ship's position, and providing alarms and indications) should be continuous. the route monitoring display covering own ship's position immediately by single operator action.	Both a second chart view and the capability to offset the image of own ship were valued for look ahead. Warnings were among the features most frequently recommended by the participating mariners. (Section 6.4) Several mariners mentioned a need for a "panic button" that would return the display to something immediately usable.
10.5.3 ECDIS should give an alarm if , within a specified time set by the mariner, own ship will cross the safety contour.	
10.5.4 ECDIS should give an alarm if, within a specified time set by the mariner, own ship will cross the boundary of a prohibited area or a geographical area for which special conditions exist. (See Appendix 4.)	
10.5.5 An alarm should be given when the specified limit for deviation from the planned route is exceeded.	
10.5.6 The ship's position should be derived from a continuous positioning system of an accuracy consistent with the requirements of safe navigation. A second independent positioning method of a different type should be provided; ECDIS should be capable of identifying discrepancies between the two systems.	The major factor in the reduction in workload is the automation of position fixing that allows navigation "at a glance." (Section 5.3, 5.4) Mariners were extremely concerned with the accuracy of all aspects of the display. (Section 6.1)
10.5.7 ECDIS should provide an indication when the input from the position fixing system is lost. ECDIS should also repeat, but only as an indication, any alarm or indication passed to it from a positioning fixing system.	Warnings were among the features most frequently recommended by the participating mariners. (Section 6.4)
10.5.8 An alarm should be given by ECDIS if the ship, within a specified time or distance set by the mariner, will reach a critical point on the planned route.	

10.5.9 The positioning system and the SENC should be on the same geodetic datum. ECDIS should give an alarm if this is not the case.	
10.5.10 It should be possible to display alternate routes in addition to the selected route. The selected route should be clearly distinguishable from the other routes. During the voyage, it should be possible for the mariner to modify the selected sailing route or change to an alternative route.	
10.5.11 It should be possible to display: .1 time labels along ships track manually on demand and automatically at intervals selected between 1 and 120 minutes; and .2 an adequate number of: points, free movable electronic bearing lines, variable and fixed range markers, and other symbols required for navigation purposes as specified in Appendix 3.	A frequently requested feature was Estimate Time of Arrival (ETA) to a point indicated with the cursor. Most mariners wanted the option of displaying or not displaying past track. Past track data on the display caused a problem when a run was repeated without turning off the system. The capability to immediately remove (and/or store) a past track would be important to ferry operations.
10.5.12 It should be possible to enter the geographical coordinates of any position and then display that position on demand. Also, it should be possible to select any point (features, symbol or position) on the display and read it's geographical coordinates on demand.	Mariners were not concerned with lat/long position except when it was needed to communicate to another ship.
10.5.13 It should be possible to adjust the ship's geographic position manually. This manual adjustment should be noted alpha-numerically on the screen, maintained until altered by the mariner and automatically recorded.	

10.6 Voyage Recording	
10.6.1 ECDIS should store and re-produce certain minimum elements required to reconstruct the navigation and verify the official database used during the previous 12 hours. The following data shall be recorded at 1 minute intervals: .1 to ensure a record of own ship's past track: time, position, heading, and speed; and .2 to ensure a record of official data used: ENC source, edition, date, cell and update history.	
10.6.2 In addition, ECDIS should record the complete track for the entire voyage, with time marks at intervals not exceeding 4 hours.	
10.6.3 ECDIS should have a capability to preserve the record of the previous 12 hours and the voyage track.	

11. ACCURACY	
11.1 The accuracy of all calculations performed by ECDIS should be independent of the characteristics of the output device and should be consistent with SENC accuracy.	
11.2 Bearings and distances drawn on the display or those measured between features already drawn on the display should have an accuracy no less than that afforded by the resolution of the display.	

12. CONNECTIONS WITH OTHER EQUIPMENT	
12.1 The ECDIS should not degrade the performance of any equipment providing sensor inputs. Nor should the connection of optional equipment degrade the performance of ECDIS below this standard.	
12.2 ECDIS should be connected to systems providing continuous position fixing, heading and speed information.	

13. MALFUNCTION WARNINGS AND PERFORMANCE TESTS	
13.1 ECDIS should be provided with means for either automatically or manually carrying out on board tests of major functions. In case of a failure, the test should display information to indicate which module is at fault.	
13.2 ECDIS should provide suitable alarm or indication of system malfunction.	Warnings were among the features most frequently recommended by the participating mariners. (Section 6.4)

14. BACK-UP ARRANGEMENTS	
14.1 Adequate back-up arrangements should be provided to ensure safe navigation in case of ECDIS failure. .1 Facilities enabling a safe take-over of the ECDIS functions should be provided to avoid that an ECDIS failure develops into a critical situation. .2 A back-up arrangement facilitating means for safe navigation of the remaining part of the voyage in case of ECDIS failure should be provided.	

15. **POWER SUPPLY**	
15.1 It should be possible to operate the ECDIS and all equipment necessary for its normal functioning when supplied by an emergency source of electrical power in accordance with the appropriate requirements of Chapter II-1 of the 1974 SOLAS Convention.	
15.2 Changing from one source of power supply to another or any interruption of the supply for a period of up to 45 seconds should not require the equipment to be manually re-initialized	